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Department of Agriculture
and Fisheries for Scotland

The Bridger Version of the Gulf III High Speed Plankton Sampler

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Introduction

The original plankton samplers in the 'Gulf' series were designed by the United States Fish and Wildlife Service's Gulf Fishery Investigations (Gehringer, 1962). The Gulf III (Gehringer, 1952) was basically a conical monel metal net enclosed in a monel metal cylinder of 502 mm diameter; the mouth of the cylinder was reduced by a removable nose-piece to a diameter of 407 mm, while a removable tail section housed a flowmeter. Since this sampler could be towed at speeds in excess of 5 knots, and since the towing cable attachment was behind the mouth, it was believed that it gave a better estimate than other samplers of the abundance of the more agile zooplankters and, following various tests and modifications described by Bridger (1958), became widely used.

Since 1957 the Bridger version of the Gulf III (and increasingly since 1969 the Dutch version) has been used by the Marine Laboratory, Aberdeen, for many of the larval fish and other zooplankton investigations. It may be useful therefore to put on record a detailed account of the Marine Laboratory's use of this sampler during 1957-68, and of tests made on its performance.

Reference is made to four Fishery Research Vessels. Descriptions of two of them, FRV 'Explorer' and FRV 'Mara' will be found in 'Oceanographic Vessels of the World Volume II' (IGY World Data Centre A for Oceanography and the National Oceanographic Data Centre 1966. Publication G-2 in the NODC General Series). The other two vessels, FRV 'Scotia' (a 50 m converted Shakesperian Class naval trawler) and FRV 'Clupea' (a 23 m converted naval motor fishing vessel) were replaced in 1971 and 1968 respectively with new vessels bearing the same names.

The main outline of this report was written in 1965-66, stimulated by the activities of an ICES, SCOR, UNESCO Working Group on the standardization of zooplankton sampling methods at sea (SCOR Proceedings Vol. 2, 1966; Fraser, 1966). Some parts of it were given previously at the Symposium on Hydrodynamics of Zooplankton Sampling in Sydney in February 1966 (Tranter, 1966; Vannucci, 1968) and to a Challenger Society Meeting held at Aberdeen in April 1967 (Adams, 1968).

Specifications of the Bridger version of the Gull III sampler and its associated equipment

The samplers used by the Marine Laboratory had a reducer nose-piece with an aperture of 203 mm diameter and a hinged 'tail' or exhaust section (Bridger, 1958). The outer casing was constructed of 1/16 in. (1.59 mm) sheet iron, galvanised after manufacture, giving a final thickness of 1/12 in. (2.12 mm). The net or filtering 'cone' was of monel metal gauze of either 40 or 60 meshes to the linear inch. The total weight of the sampler was approximately 175 lb (79.4 kg) in air.

The dimensions of the sampler are given in Figure 1.

The monel metal gauze was as follows:

60 meshes to the linear inch - thickness of wire, 0.16 mm;
aperture, 0.38 mm diagonal,
0.27 mm width.

40 meshes to the linear inch - thickness of wire, 0.23 mm;
aperture, 0.57 mm diagonal,
0.40 mm width.

The side fins were often removed with no apparent effect on the performance of the sampler. From about 1964 the samplers were fitted with a dorsal fin of 5/16 in. (8 mm) thick Balata machine belting.

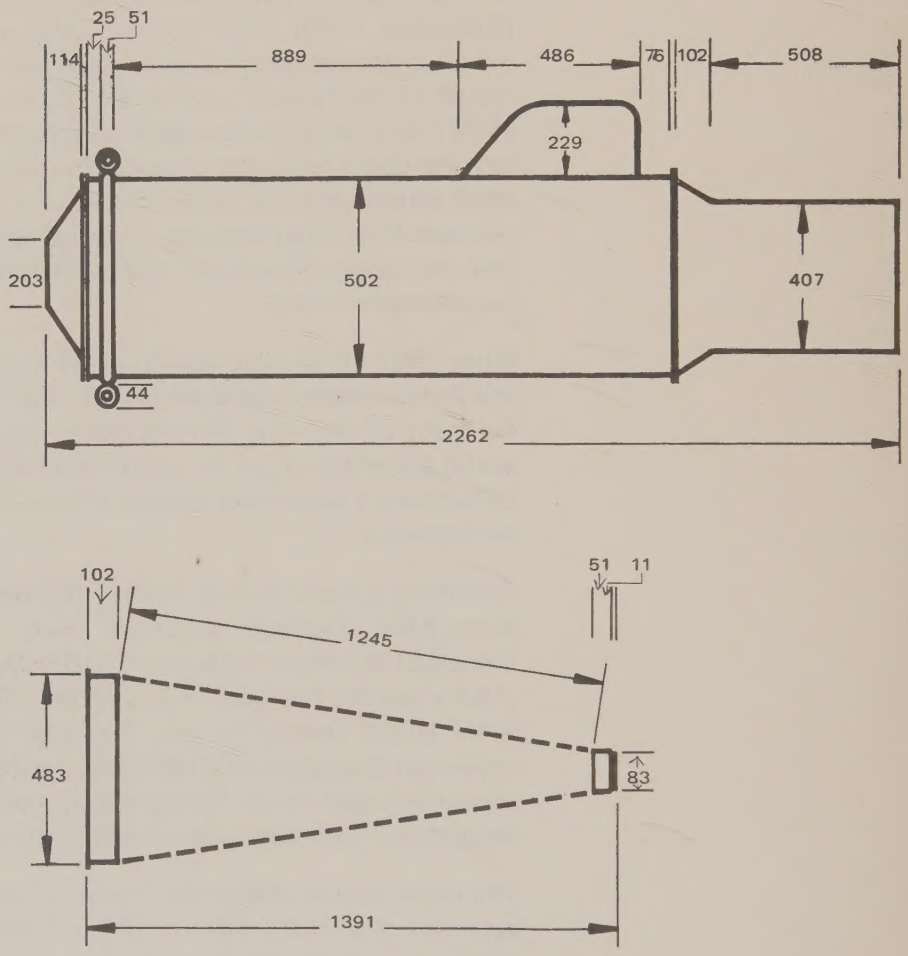


Figure 1. Dimensions (mm) of the Bridger version of the Gulf III high speed plankton sampler.

The Cod-End

A number of Gulf IIIs used by the Marine Laboratory had a monel metal bucket cod-end as described by Gehringer (1952). Since, during recovery of the sampler, part of the sample was liable to flow back into the net, the metal bucket was replaced by a silk (later nylon) bag cod-end of 60 meshes to the linear inch.

Although the sild cod-end was introduced as early as 1958, the metal bucket was still used up to April 1960. Details of the type of cod-end used were unfortunately seldom recorded. Calculations based on the samples obtained using a bucket cod-end gave a lower estimate of zooplankton standing stock than those based on samples obtained using a silk cod-end. For instance,

eight replicate hauls with a silk bag cod-end gave an average of 2.52 g dry weight/100 m^3 (range 1.87-3.42) compared with an average of 0.61 g/100 m^3 (range 0.14-1.16) for three hauls on the same occasion with a monel metal bucket, a ratio of 4.1:1. These results were the basis of the statement by Steele (1961) that "a metal bucket with a mesh window has since been found to give extremely small collections compared with a silk bag".

Further hauls to test the difference between the two types of cod-end were carried out by Adams (1962). Nine hauls were obtained with a bag and eight with a metal bucket. The dry weight values in this experiment indicated a ratio of 1.80 between the catches of the two cod-ends. Individual ratios for the constituent species ranged from 1.08 to 2.15.

The differences between the results of these experiments are difficult to explain and complicate any discussion of the causes of the difference between bucket and bag which, under the conditions of the experiments, could not have been due to the sample from the bucket flowing back into the filtering "cone"; furthermore, there was no evidence that the Gulf III fitted with a bucket filtered less water than the Gulf III with a bag cod-end. The cause of the difference is obscure.

The Towing Warps

The specifications of warp used for towing the Gulf III from various Fishery Research Vessels were:

FRV 'Clupea' and FRV 'Scotia'

10 mm diameter, 6 stranded, 19 wires per strand, fibre core, galvanised best plough steel of 140-150 kg/mm^2 tensile strength, breaking strain 5 t.

FRV 'Explorer'

As for FRV 'Clupea' and FRV 'Scotia', but 11 mm diameter and 6 t breaking strain.

FRV 'Mara'

As above, but 13 mm diameter and of 9 t. breaking strain.

Swivels

Swivels were always used on FRV 'Explorer' and FRV 'Clupea' but on FRV 'Scotia' only during 1962 and 1963. Various swivels were tried. From mid-1963 brass swivels with stainless steel ball bearings (Alpine Geophysical Associates' swivel No. 703) gave good service until October 1968, when a fracture was found in the same part of the eye bolt of each swivel; one sampler was lost as a result. These fractures were probably caused by a slight bending of the swivel when being brought up to the towing block.

In late 1968 the brass swivels were replaced by stainless steel swivels (Boss Products swivel No. SW50S).

Depressor

Throughout the period the Scripps homogeneous depressor (Isaacs, 1953) - also known as the Isaacs-Kidd depressor - was used, attached at the end of a 1.5 to 3.0 m strop.

Drogue

In February 1966 the use of a drogue was introduced on FRV 'Explorer' to reduce the chance of collision of the Gulf III with the ship's stern. The drogue (Fig. 2) was based on specifications supplied by the Fisheries Laboratory, Lowestoft.

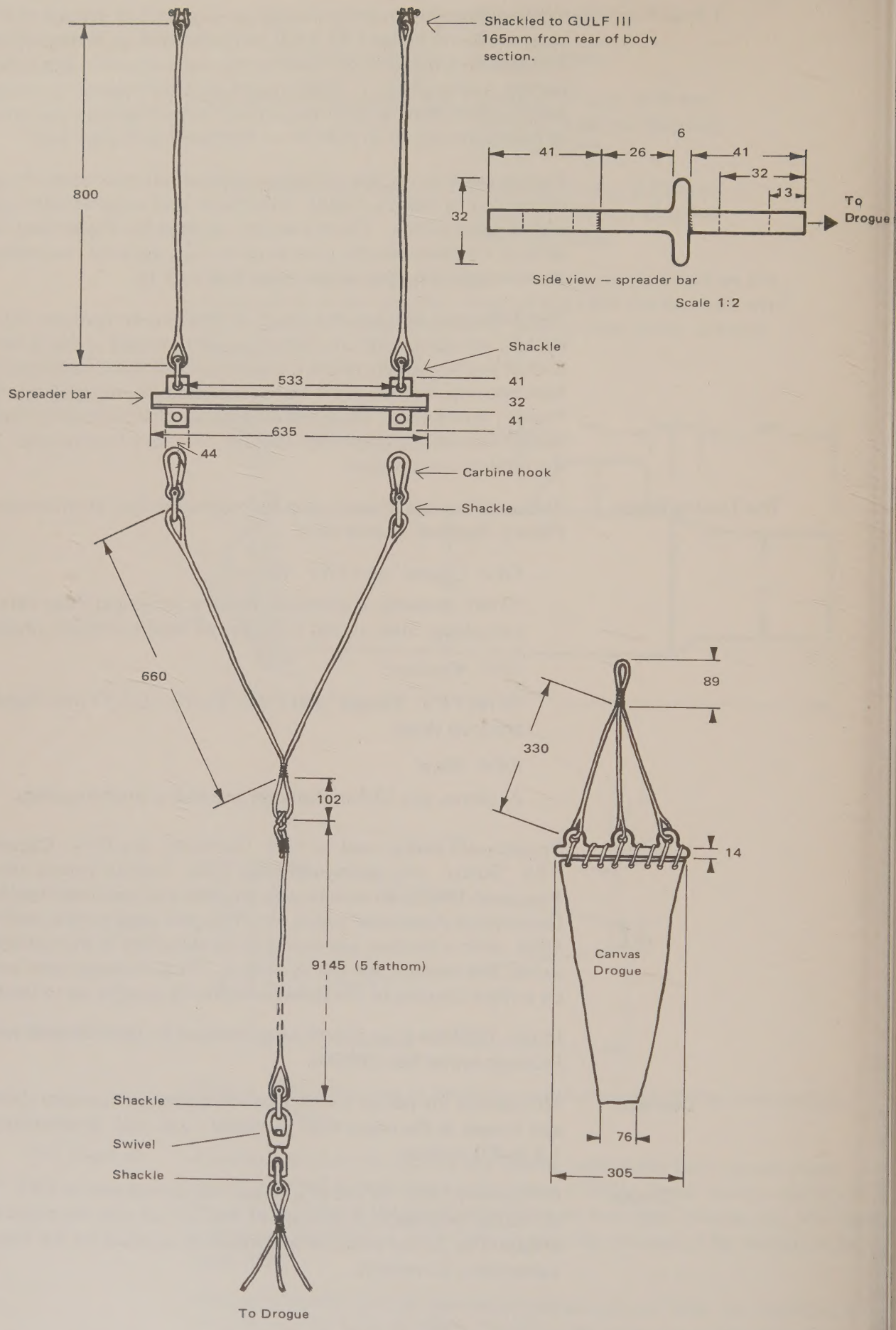


Figure 2. Specifications of the drogue and associated gear used with the Bridger version of the Gulf III on FRV 'Explorer'. All dimensions in mm.

Handling FRV 'Scotia' and FRV 'Explorer'

The ship proceeded on course at a constant speed of 6 knots while the Gulf III was launched and the required length of towing warp paid out at a constant warp speed of 40 m/min (i.e. prior to 1967 - see page 6). On completion of shooting the Gulf III was immediately hauled in also at 40 m of warp/min.

When first used from FRV 'Scotia', the Gulf III was shot from a davit at the port quarter, and between hauls stored in a cradle fixed to the ship's rail.

The warp left the winch on the boat deck at a sharp angle and was led to the davit in a Z-shaped form. This, and the strain in the warp, prevented the spreader mechanism from working properly and the warp piled up at one place on the drum. Between stations the warp had to be streamed behind the ship and rewound.

The port davit was eventually replaced by stern gallows at main deck level, a most satisfactory arrangement. Between hauls the Gulf III was stowed on deck and later an angled cradle was provided which allowed draining of the sample to continue after the Gulf III was on board.

On FRV 'Explorer' the Gulf III was, for one cruise, used from the forward trawl gallows on the starboard side. Although satisfactory in calm conditions, this was unsuitable in wind or swell. Subsequently a stern gallows was fitted adjacent to a winch on the boat deck.

A cradle was provided on deck.

FRV 'Clupea'

On FRV 'Clupea' the ship's speed was also 6 knots during shooting, but was reduced to about three knots for recovery. In addition, the Gulf III was shot by allowing it to run out under its own weight, while tension was maintained in the warp by slight application of the winch brake. Approximately ten minutes after the beginning of shooting the Gulf III was hauled in, giving a haul of at least ten minutes total duration.

The Gulf III was always operated from the aft trawl gallows, the warp being led from a trawl winch on the foredeck. To ease the removal of the cod-end, an aperture was cut in the side of the body casing of the Gulf III and at a later date ease of access was achieved by removing the 'tail' section. Between hauls the Gulf III was normally stowed along the rail of the ship.

FRV 'Mara'

As on FRV 'Clupea', the trawl winch was used and the sampler deployed from the aft trawl gallows.

Losses

During 1957-68 five Gulf III samplers were lost from FRV 'Clupea' and two from FRV 'Scotia'. The first loss from FRV 'Clupea' was due to a break in the towing warp of which 220 metres were lost. In consequence a nylon 'link' rope (of lower breaking strain than the warp) or double wire strops, (which acted as a shock absorber) were inserted between the sampler and the towing warp). Further losses from 'Clupea' were due to the breakage of links or swivels associated with the 'link' rope or wire strops. Later the Gulf III was attached directly to the towing warp by means of a swivel, one of which also broke.

The losses from FRV 'Scotia' were due to breakage of the towing warp.

Laboratory Tests of the Breaking Tension in the Towing Warp

Metal fatigue was believed to be responsible for the early losses and instructions were issued to cut off the end portion of the towing warp at frequent intervals. During 1964 to 1968 the cut-off portions of warp were tested. The results of these tests suggest that the warps maintained their breaking strengths throughout the period of use.

Field Measurements of the Tension in the Towing Warp

The warp tension was measured on FRV 'Mara' when towing the Gulf III at a constant depth and when hauling. When towing the strain was remarkably steady at about 0.40 to 0.45 t; hauling increased the load to a maximum of about 0.60 t.

The tension when towing at a constant depth was also measured on FRV "Explorer" using an "Elliot" deck load cell (Table I). Although the maximum length of warp tested was only about 450 m (compared with a maximum on most cruises of 737 to 760 m and an extreme maximum of 1,100 m), Table I suggests that at 6 knots the tension does not normally exceed 0.5 t.

Table I

Tension in Gulf III towing warp in relation to speed and warp length

Length of warp (m)	Ship's speed (knots)	Tension (t)
30	4.0	0.12
	4.8	0.15
	5.9	0.20
	6.3	0.25
	7.0	0.27
	8.0	0.36
250	4.9	0.20
	5.8	0.24
	6.4	0.33
	7.6	0.39
	8.2	0.46
450	1.8	0.07
	5.2	0.25
	6.0	0.31

Shooting and Hauling Warp Speeds

As noted above, the recommended shooting and hauling warp speed was 40 m/min. The Marine Laboratory's record of plankton hauls, however, shows that the average shooting-hauling warp speed, calculated from the time taken to shoot and haul, tended to be greater as the length of warp out increased. This was probably a result of the winch operators trying to reduce the duration of deep hauls by increasing the speed of the winch.

Table II gives the shooting-hauling warp speeds calculated for hauls from FRV 'Clupea', FRV 'Scotia' and FRV 'Explorer'.

In January 1967 the recommended shooting warp speed was increased to 70 m/min on FRV 'Scotia' and FRV 'Explorer'. Later that year, in an attempt to sample each depth at the same intensity, shooting and hauling warp speeds were varied, on occasion, according to the length of warp out, using a tachometer to measure the warp speed. The speeds were 25 m/min at 0-75 m warp, 40 m/min at 75-200 m warp and 50 m/min at >200 m warp. In the absence of a tachometer the correct warp speeds were rarely, if ever, achieved (Fig. 3b).

Table II

Average shooting-hauling warp speed (m/min) for Gulf III hauls using different lengths of warp

Ship	Period	Warp length in metres										
		1–99	100–199	200–299	300–399	400–499	500–599	600–699	700–799	800–899	900–999	⟩1,000
'Clupea'	1957–60	11.1	24.7	36.5	44.0	–	74.6	–	–	–	–	–
	1961–65	11.4	28.6	40.9	49.0	66.6	69.8	–	–	–	–	–
'Scotia'	1957–60	21.0	27.4	30.5	37.4	46.2	45.6	41.9	52.9	47.4	–	–
	1961–66	29.2	43.4	48.8	54.3	57.8	60.5	65.3	66.7	58.8	65.6	59.8
	*1967	36.4	39.0	42.2	47.8	48.5	49.3	–	56.9	–	–	–
'Explorer'	1957–60	23.4	38.1	47.2	54.7	62.4	–	–	–	–	–	–
	1961–66	29.8	39.9	45.2	48.9	49.2	49.8	56.8	53.6	–	–	–
	1967	29.2	43.3	46.5	49.7	57.0	48.2	–	–	–	–	–

*September survey excluded.

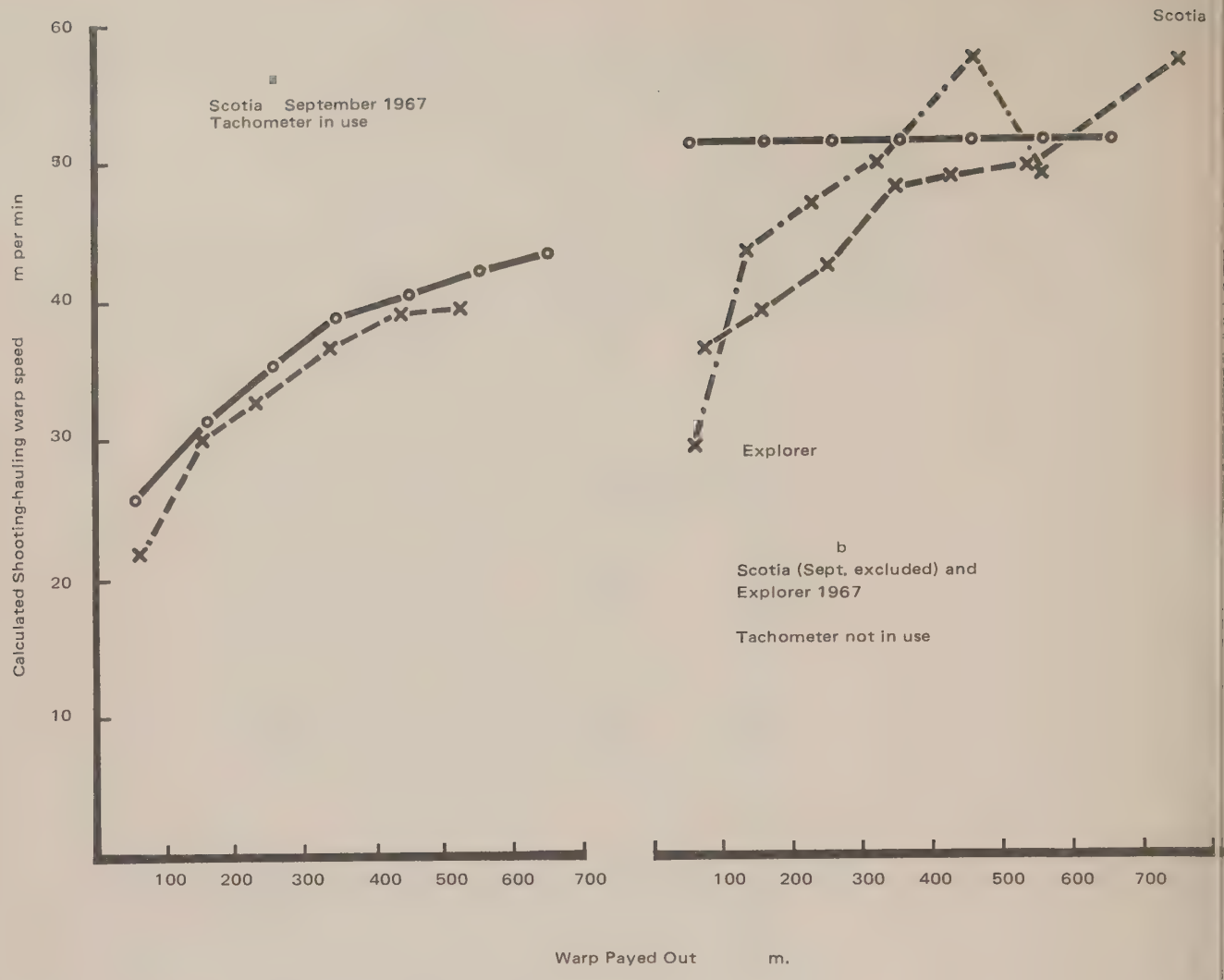


Figure 3. Average shooting-hauling warp speed at various warp lengths.
Planned O——————O; actual X– – – – – – – – –X.

Calculations of the shooting-hauling warp speed assume a constant warp speed throughout the duration of the haul, but this was largely an incorrect assumption. Timing the duration of shooting and hauling separately on FRV 'Scotia' gave the results shown in Figure 4.

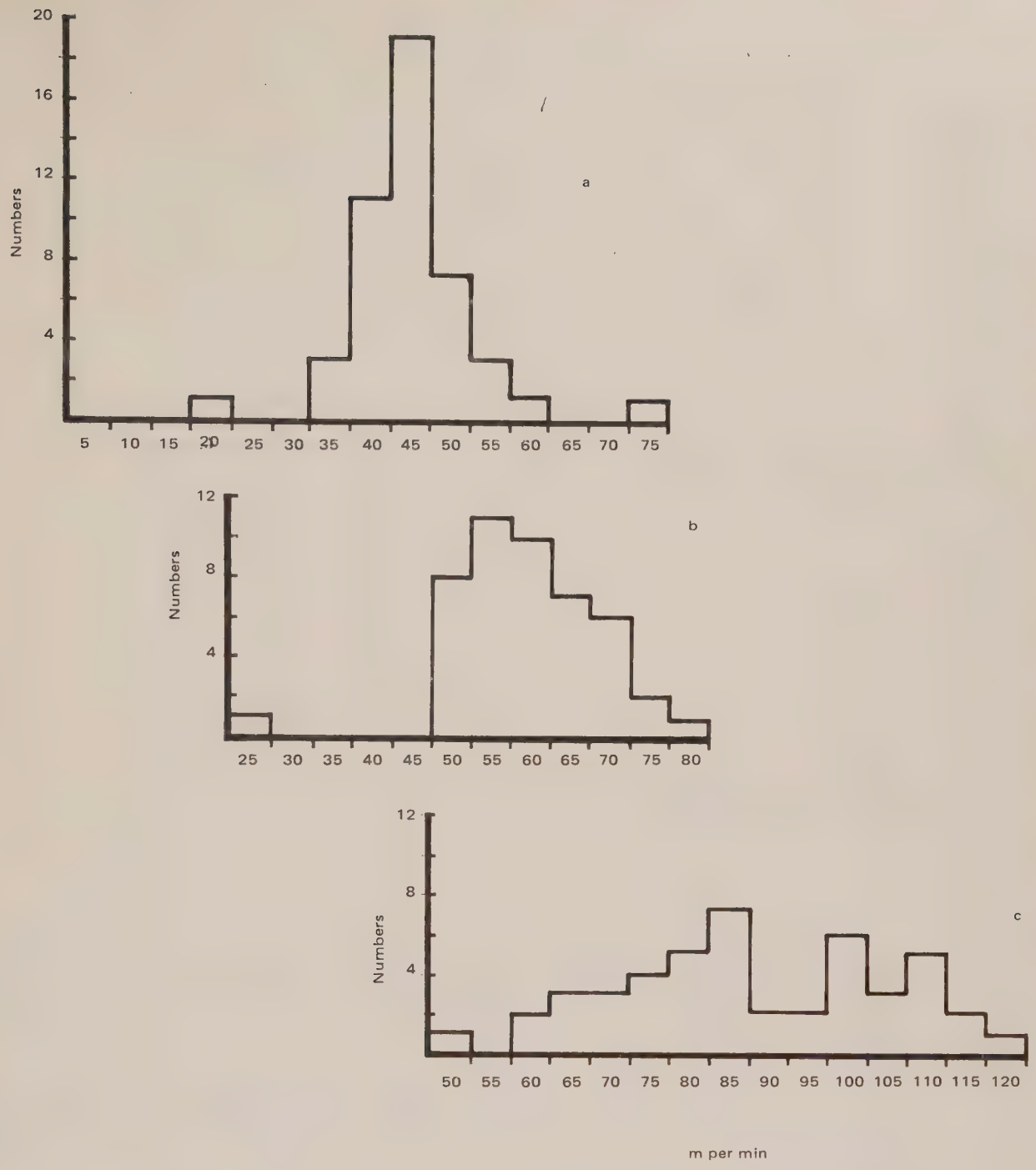


Figure 4. Frequency distributions of (a) hauling warp speeds and (c) shooting warp speeds compared with (b) the distribution of the average warp speeds of shooting and hauling combined for the Gulf III on FRV 'Scotia', July 1966.

From these data the following ratios were calculated.

$$\frac{\text{Actual shooting warp speed}}{\text{Calculated shooting-hauling warp speed}} = 1.47$$

$$\frac{\text{Actual hauling warp speed}}{\text{Calculated shooting-hauling warp speed}} = 0.77$$

These ratios probably also applied to hauls from FRV 'Explorer', but not to those from FRV 'Clupea' where the shooting and hauling procedure was different. Data obtained on FRV 'Clupea', where the amount of warp out ranged from 46 to 229 m, are shown in Figure 5. There is some indication that the shooting speed (average 139 m/min) increased with length of warp through the hauling speed was less variable (average 28 m/min).

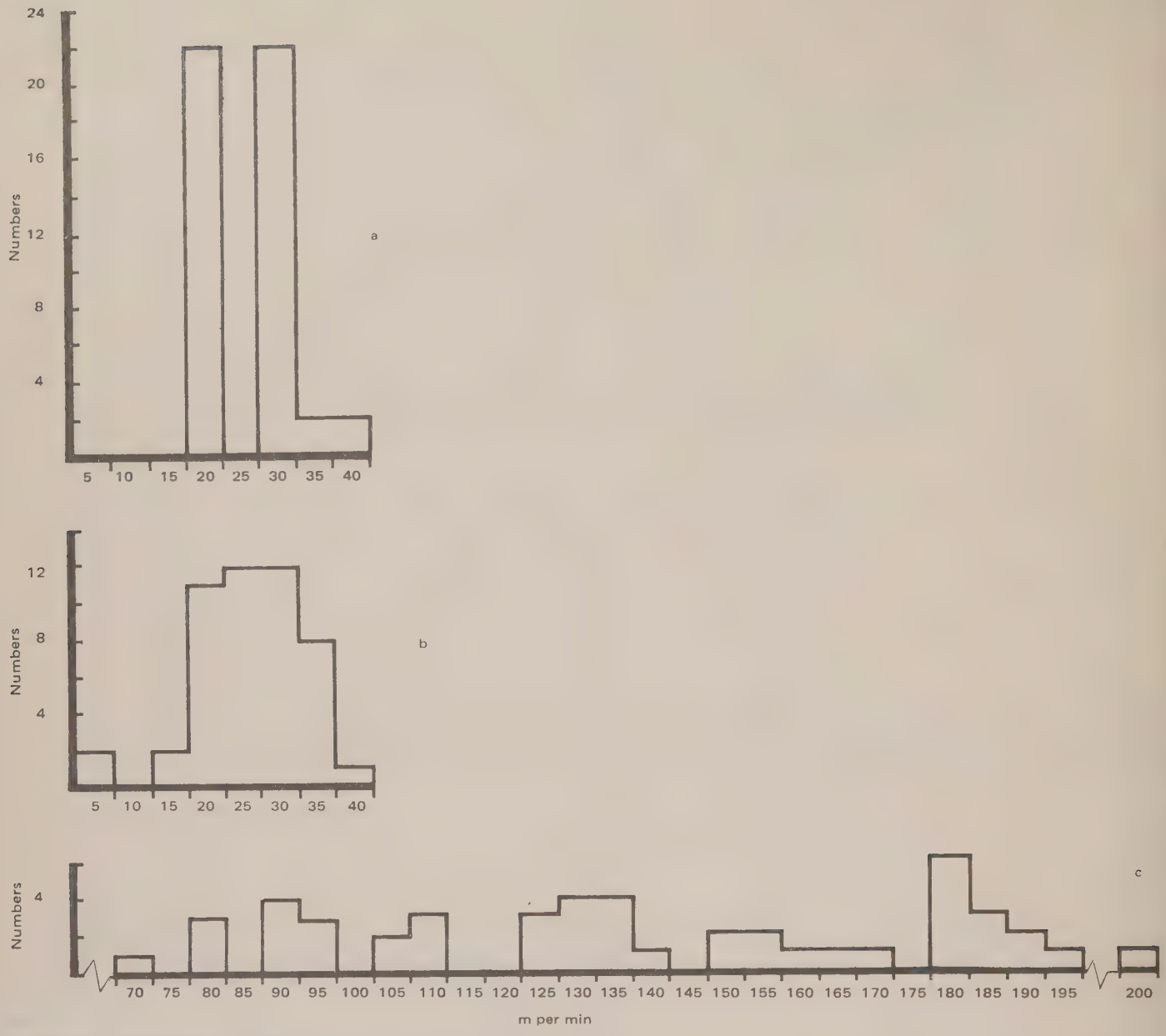


Figure 5. Frequency distributions of (a) hauling warp speeds and (c) shooting warp speeds compared with (b) the distribution of the average warp speeds of shooting and hauling combined for the Gulf III on FRV 'Clupea', September 1966.

Depth of Operation and its Determination

From 1957 to 1960 an attempt was made to shoot the Gulf III within three or four metres of the sea bed, at least when working in depths of 200 m or less. The warp length to depth relationship (three to one) then in use suggests that this was rarely achieved. From late 1961 the sampler was aimed to reach within 10 m of the sea bed at the bottom of its tow. The data obtained during 1962-65 (Fig. 6) show that the depth reached was generally within 15 to 20 m of the sea bed, but that some hauls were much closer to the sea bed, and others considerable distances above. In January 1967 a new length of warp to depth table was introduced which incorporated a safety factor such that the sampler, on average, reached between 11 and 32 m from the sea bed (see next section). The safety factor was considered desirable to reduce to an acceptable minimum the number of samples contaminated with sand and mud when the Gulf III hit bottom.

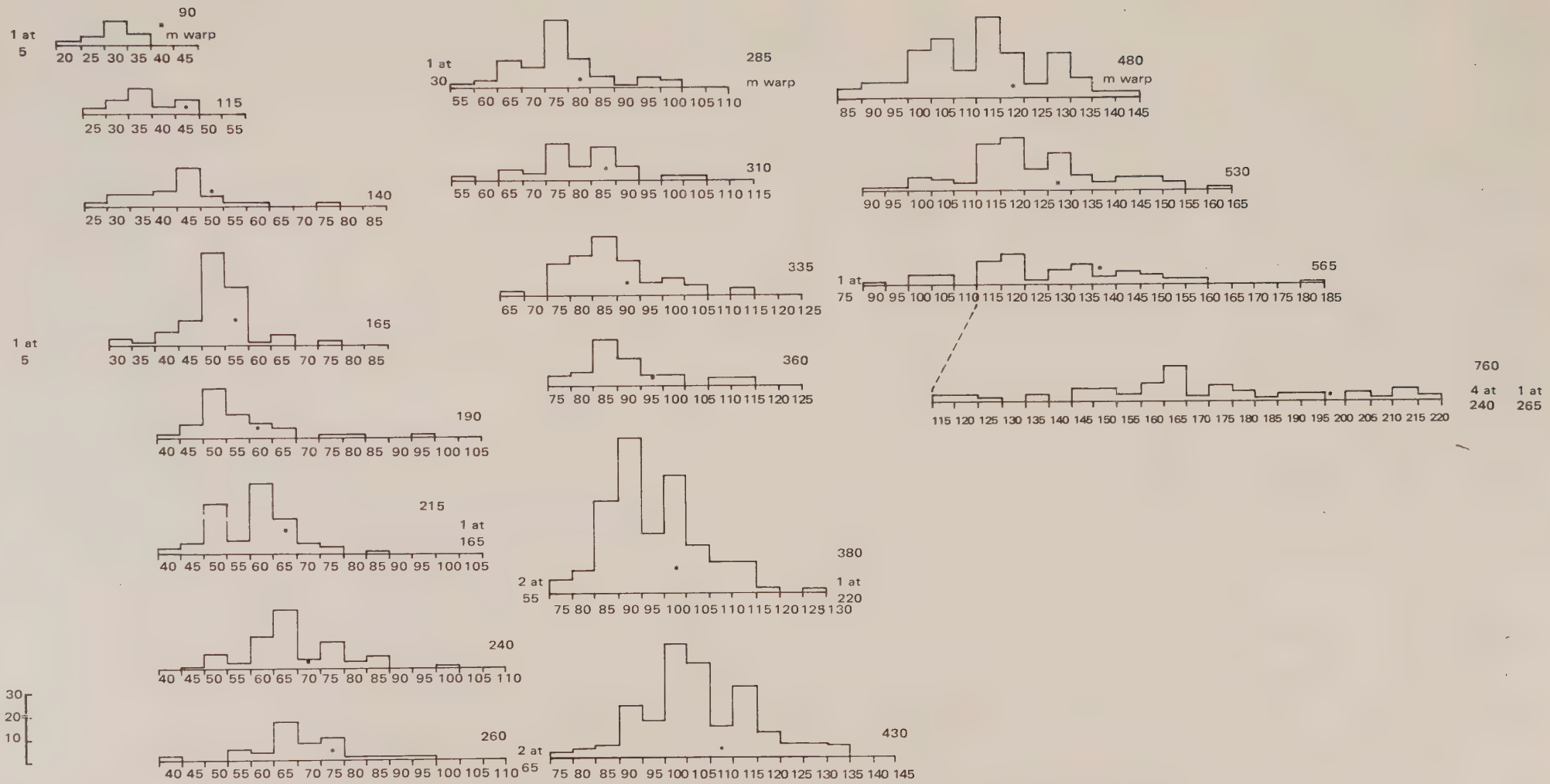


Figure 6. Frequency distributions of the depth reached by the Gulf III for various lengths of warp out – FRV 'Scotia', 1962-65. The depth to which it was hoped the sampler would go for each length of warp indicated is shown thus – *. For lengths of warp less than 380m this depth should be about 10m less than bottom depth, and for lengths of warp greater than 430m it should be from 10 to 15m less than bottom depth. Depths attained which appear to be greater than the bottom depth will arise from (i) errors in reading the depth-flowmeter record; (ii) the bottom depth increasing during the course of a haul.

Further Discussion of the 1962-65 Length of Warp to Depth Data

When the data presented in Figure 6 were plotted as a scatter diagram it was obvious that (i) the relationship between warp length and depth was not linear over the depth range 25-200 m and (ii) the variability of the data was not consistent throughout the depth range.

To avoid statistical problems arising from (i) and (ii), the data were divided into three parts, and straight lines were fitted to each part separately. The divisions were made where there appeared to be a change in the variability. [This was, of course, subjective, as most probably the variability increased along the line in a systematic way, e.g. being proportional to depth.] In subsequent calculations it was assumed that the variability was uniform over the depth ranges 25-75 m, 80-145 m and 150-200 m.

Three regressions were calculated:

i) Depth range 25-75 m; $D = 0.2285L + 12.7468$

ii) Depth range 80—145 m; $D = 0.1977L + 20.8984$

iii) Depth range 150—200 m; $D = 0.2382L - 7.7394$

where L = warp length in metres and

D = depth in metres

Table III gives the average depths obtained during 1962-65 for a given warp lengths calculated from these regressions.

Table III

Length of warp and average depth attained (in metres)

Length of warp	Average depth of Gulf III	Length of warp	Average depth of Gulf III
29	19	403	100
51	24	428	106
73	29	453	110
95	34	479	116
117	39	504	120
139	44	529	126
160	49	554	130
182	54	*554	118
204	59	*554	123
226	64	569	128
*226	66	590	133
251	70	611	138
276	76	632	143
301	80	653	148
327	86	674	153
352	90	695	158
377	96	716	163
		737	168

*Duplicated values arose from discontinuities in (1) the length of warp to depth relationship and in (2) the variability of the data.

The 80% tolerance limits for the depths for the three depth ranges given above above were ± 10.6 m, ± 14.5 m and ± 32.3 m. Using these ranges a new length of warp table was prepared, providing for a given depth the required length of warp such that with a probability of 0.80 only 10% of hauls will touch the bottom.

Effect of Shooting Warp Speed on the Depth Reached

Limited data obtained on the effect of shooting warp speed on the depth reached are shown in Figure 7. The relationships shown arise from the facts that (i) during shooting the warp speed must be subtracted from the ship's speed, (ii) a change in the warp speed from 60 to 120 m/min approximately halves the speed of the sampler (Fig. 8) and (iii) the sampler becomes more sensitive to changes in speed as the length of warp is increased (Aron, Ahlstrom, Bary, Bé and Clarke, 1965).

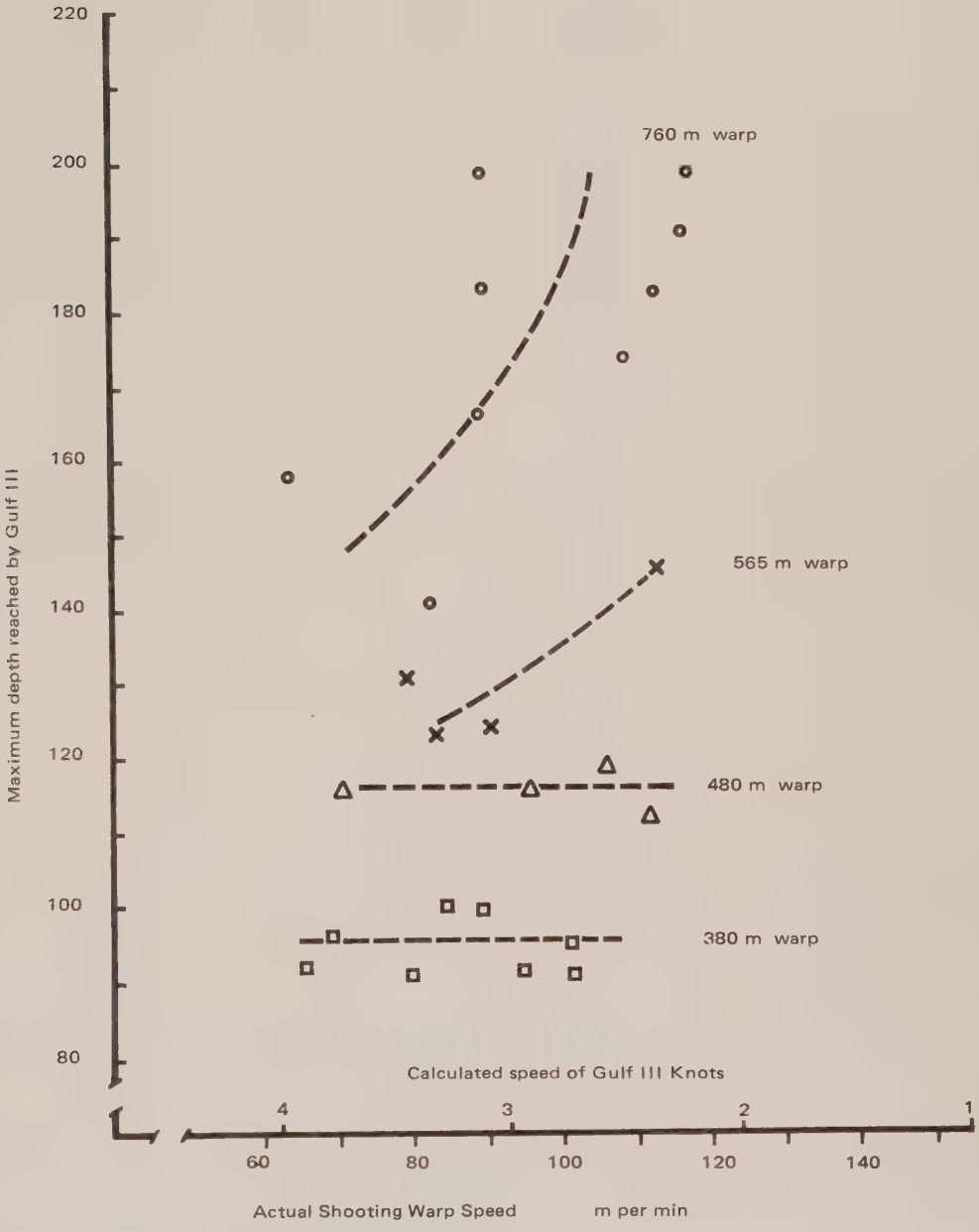


Figure 7. Variation in maximum depth reached by the Gulf III in relation to shooting warp speed and length of warp out.

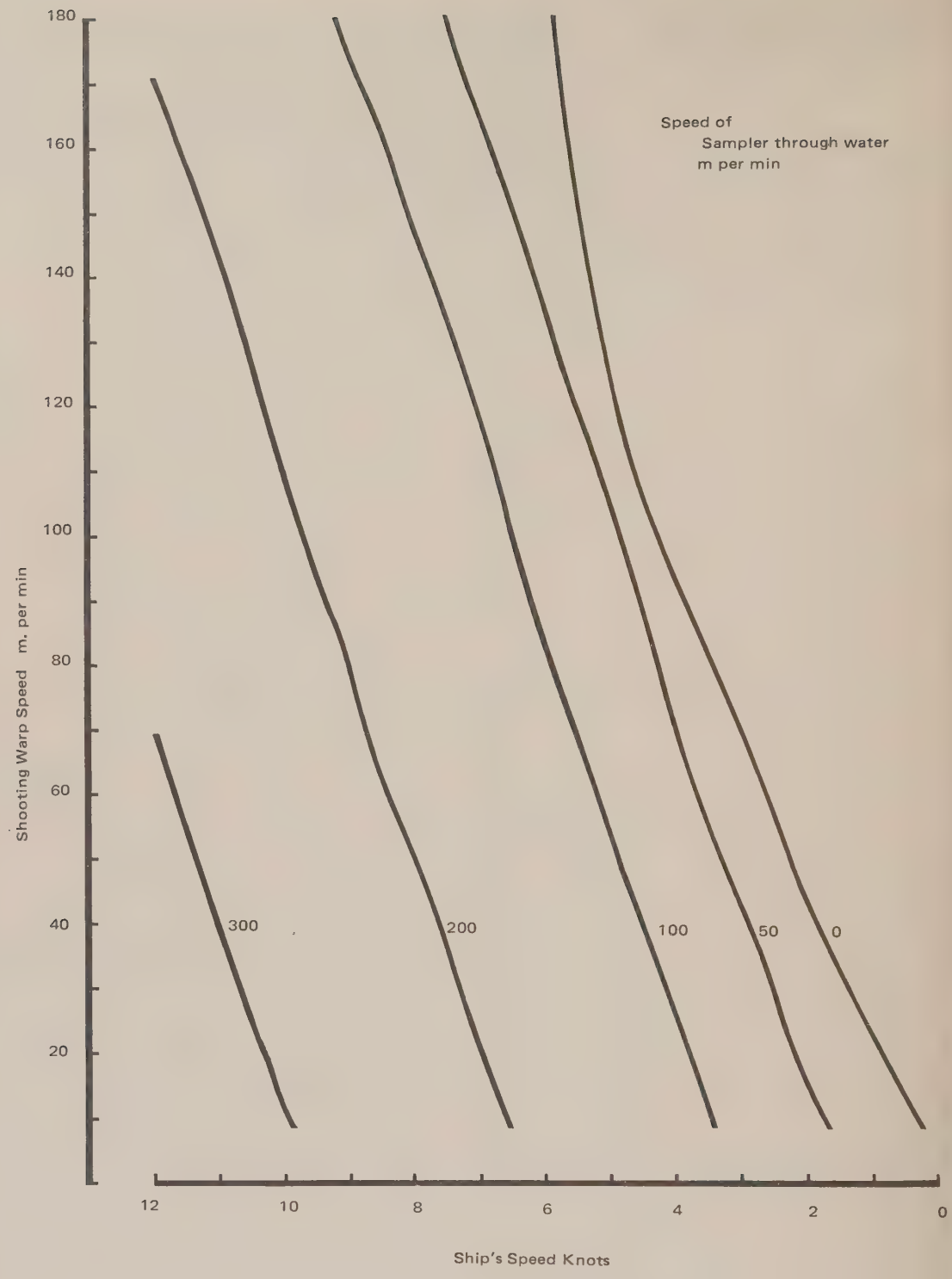


Figure 8. Speed of sampler through the water in relation to ship's speed and shooting warp speed.

It is possible from an examination of Currie-Foxton depth flowmeter records also to calculate the vertical distance the Gulf III rose in the water just as hauling started (Fig. 9). This rise is due to the sudden increase in sampler speed and as expected from Figure 7 the rise was most marked with longer lengths of warp. From Figure 9 it can be shown that shooting at a speed of 70 m/min or less will reduce this effect.

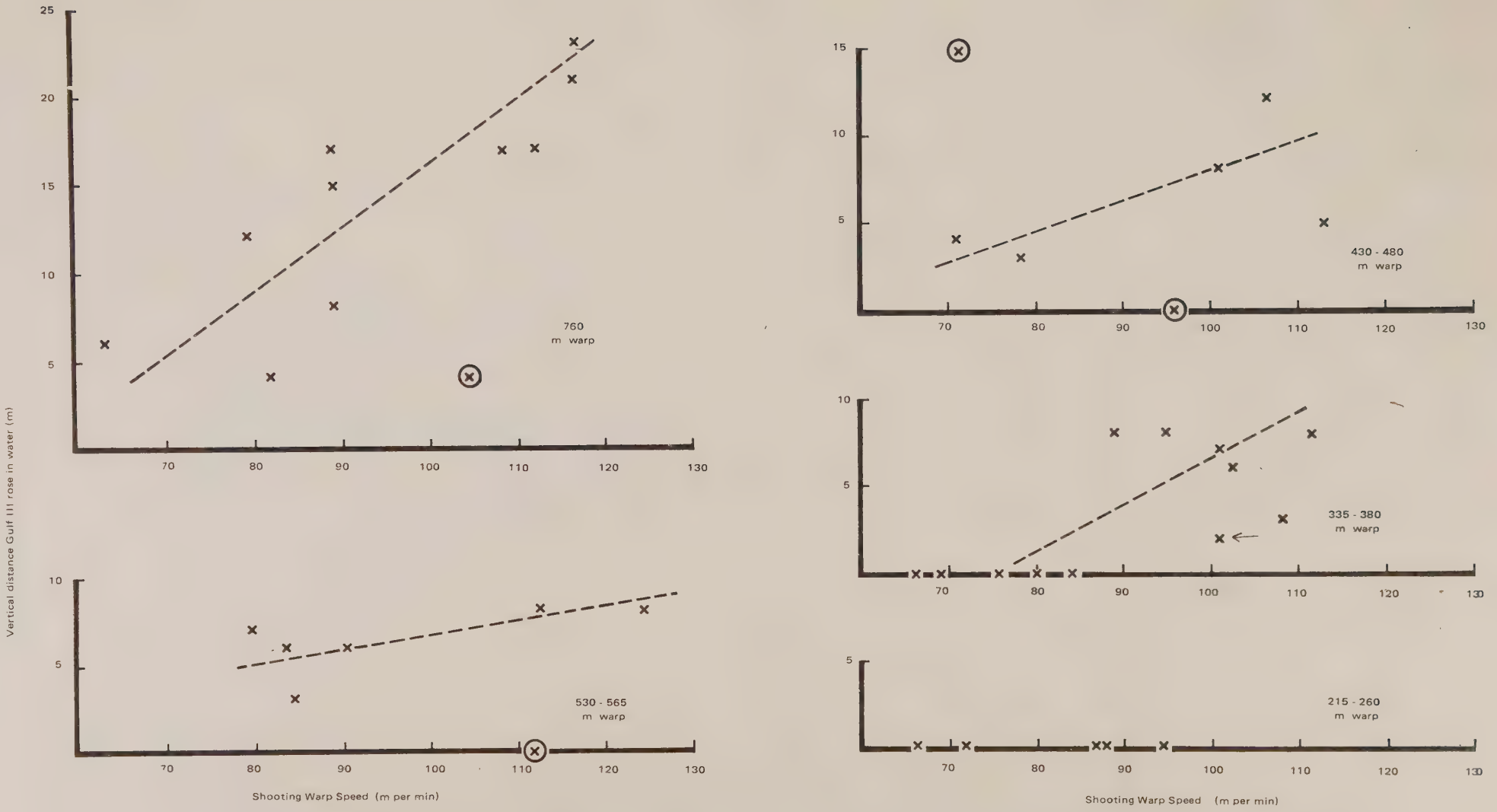


Figure 9. Variation in the vertical distance the Gulf III rose in the water as hauling commenced, in relation to shooting warp speed and warp length.

Depth Recorders

On many cruises the maximum depth of sampling was measured by means of a Currie-Foxton depth flowmeter (see below); in addition depth information could often be obtained from a bathythermograph attached to the Gulf III.

In 1963 a Gulf III was modified to take the transmitter unit of a Furuno depth telemeter and trials were conducted using a receiver designed for attachment to the warp, but towed on a separate warp attached to a Scripps depressor; only intermittent signals were received and no satisfactory results were obtained. Later a receiver designed to be attached to a depressor was used but again without success. Later examination of the Furuno showed faults in the deck unit. Although these were corrected, and encouraging results obtained, the use of the Furuno depth telemeter never became routine.

Estimation of Volume of water filtered

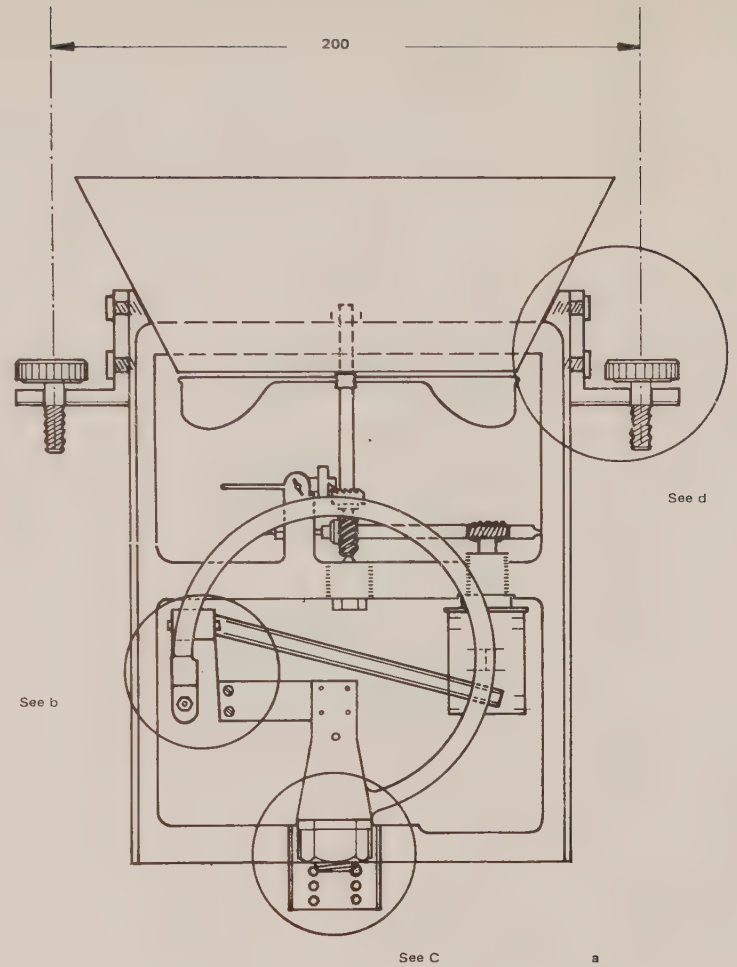
After unsuccessful trials using a Tow Net Indicator (Submerged Log Co.) and a 'Lowestoft Pattern' flowmeter, the use of a Currie-Foxton depth flowmeter (Currie and Foxton, 1957) was introduced in March-April 1959. Subsequently, this type of flowmeter was used extensively from FRV 'Scotia'. It was also used on FRV 'Explorer' but not during the period 1964-66, when problems caused by the Gulf III colliding with the high stern of the ship caused its use to be discontinued. This problem was solved in 1967 when a drogue was used.

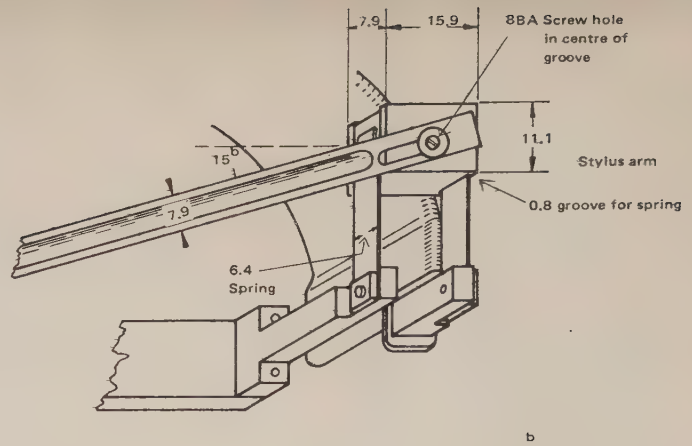
In September 1967 a TSK flowmeter (Nakai, 1954; 1962) was first used as a routine method on FRV 'Clupea'. It was then increasingly used on FRV 'Clupea' and FRV 'Explorer'.

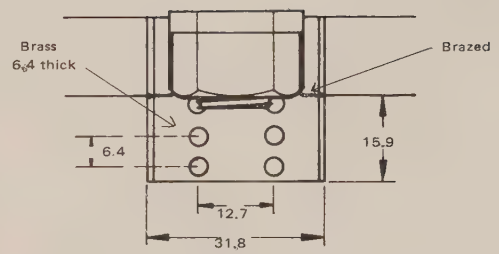
Modification to the Currie-Foxton Depth Flowmeter

A constant source of trouble when the Currie-Foxton depth-flowmeters were first used in Gulf IIIs was displacement of the stylus from the glass cylinder if the Gulf III collided with the ship's side. This was successfully overcome by recessing the stylus arm at its point of attachment to the twin flexure system (Fig. 10, Part 2b).

It was also felt desirable to be able to interchange Bourdon tubes, so that the same flowmeter could be used over a greater range of depths. Variation in the size of Bourdon tubes, associated with the recessing of the stylus arm, resulted in the stylus making contact with the smoked glass cylinder either too near the top or bottom of the cylinder to give a complete and satisfactory record. An extension of the Bourdon tube attachment point overcame this problem (Fig. 10, Part 2c). Finer adjustment was obtained by the use of washers.







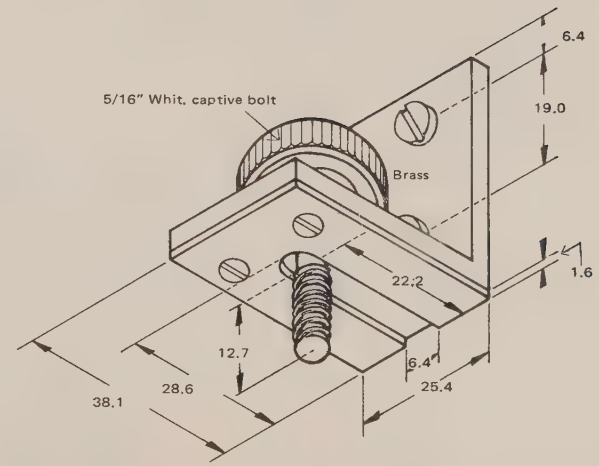


Figure 10. (a) General outline of the Currie-Foxton depth-flowmeter, as modified by the Marine Laboratory, Aberdeen, and details of (b) the attachment of stylus arm to the twin flexure system, (c) the extension to the Bourdon tube attachment and (d) the captive bolts used to secure the flowmeter in the structure shown in Figure 11. All measurements in mm.

The depth-flowmeter was originally held in place in the exhaust of the Gulf III (89 mm behind the cod-end, where the cross section area was 0.130 m^2) by a method similar to that described by Currie and Foxton (1957) i.e. by three knurled screws in a bayonet-type holder supported on three stays. The bayonet-type holder was easily distorted and instead two captive bolts (Fig. 10, Part 2d) secured the flowmeter in the structure shown in Figure 11. The ring of this structure was made of mild steel and the supporting rods of brass, both sprayed with zinc after manufacture. The flowmeter was then 25 mm behind the cod-end where the cross section area of the exhaust was 0.173 m^2.

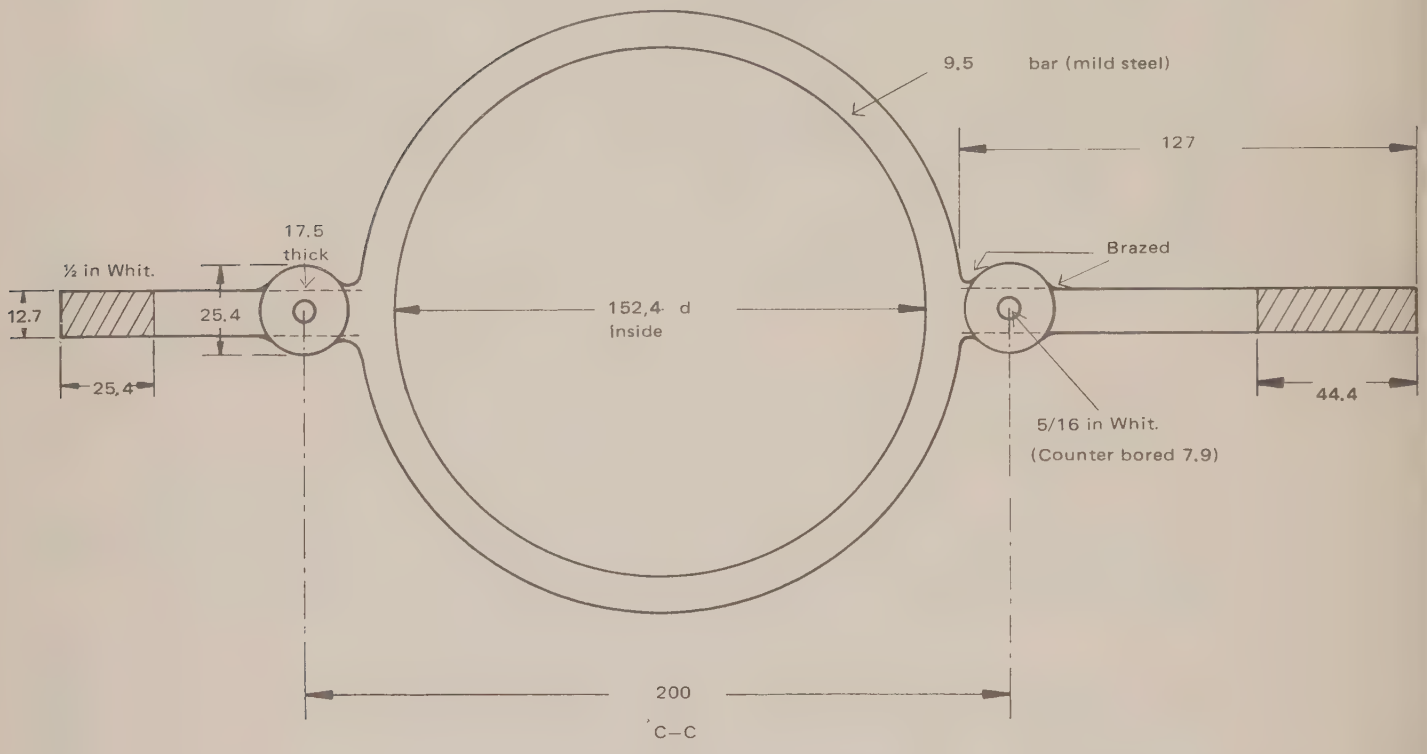


Figure 11. Support structure for holding the Currie-Foxton depth-flowmeter in the exhaust of the Gulf III. All measurements in mm.

Calibration of Currie-Foxton Depth Flowmeters

Calibration of the Currie-Foxton depth flowmeters was carried out at sea by lowering the flowmeter vertically to a known depth on hydrographic wire. The technique used differed from that recommended by Currie and Foxton in three respects: (i) the depth flowmeter was not fixed in a brass drum for the calibrations, but directly to the hydrographic wire, or in a special holder (Fig. 12); (ii) a reversing thermometer was not used to determine the depth of the flowmeter, and (iii) the revolution of the cylinder was not prevented for the depth calibration - in fact the same operation was used to obtain both a depth and a flow calibration.

Both flow and depth calibrations agreed fairly well with those reported by Currie and Foxton (1957).

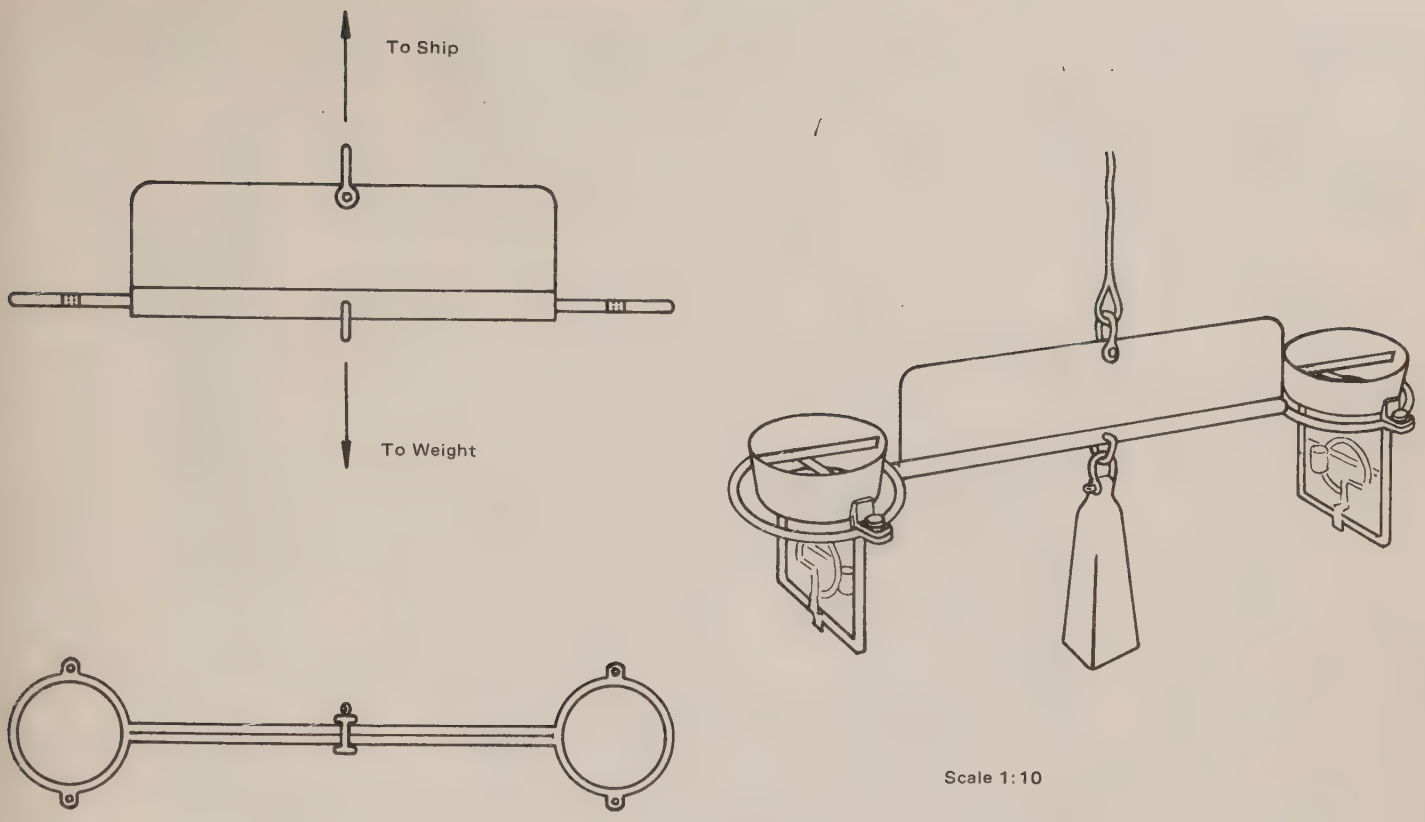


Figure 12. Holder used when calibrating Currie-Foxton depth-flowmeters at sea.

The TSK Flowmeter

The TSK flowmeter was described in detail by Nakai (1954, 1962). The TSK flowmeter was placed centrally in the Gulf III exhaust where the cross section area of the exhaust was 0.130 m^2, and held in position by two shock cords and a safety strop (Fig. 13). The safety strop was originally made of nylon but this was later replaced by phosphor bronze as the nylon proved too elastic.

No calibrations of the TSK flowmeters have been made by the Marine Laboratory. The calibrations supplied by the manufacturers have been used throughout.

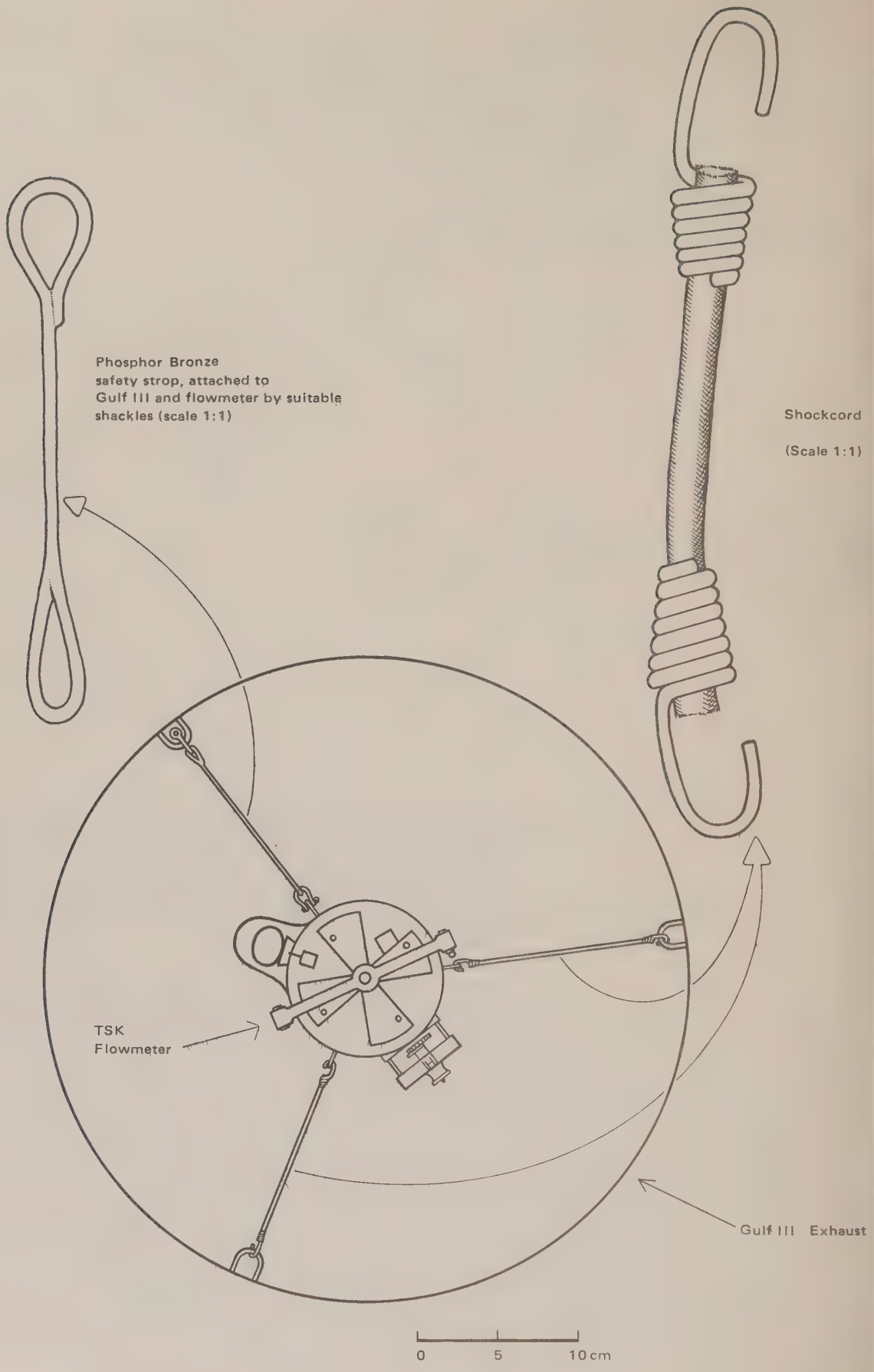


Figure 13. Details of the supports used for the TSK flowmeter in the exhaust of the Gulf III.

The Flow Profile in the Gulf III Exhaust

Although it is often assumed that the flow through a flowmeter is representative of the total flow through the part of the sampler where the flowmeter is situated, this is not necessarily so. In 1967 a number of hauls were made in which a TSK flowmeter was placed in the exhaust in one of three positions (Fig. 14), for each series of hauls the flowmeter being placed as in the sequence listed below.

A, B, C, B, C, A, C, A, B etc.

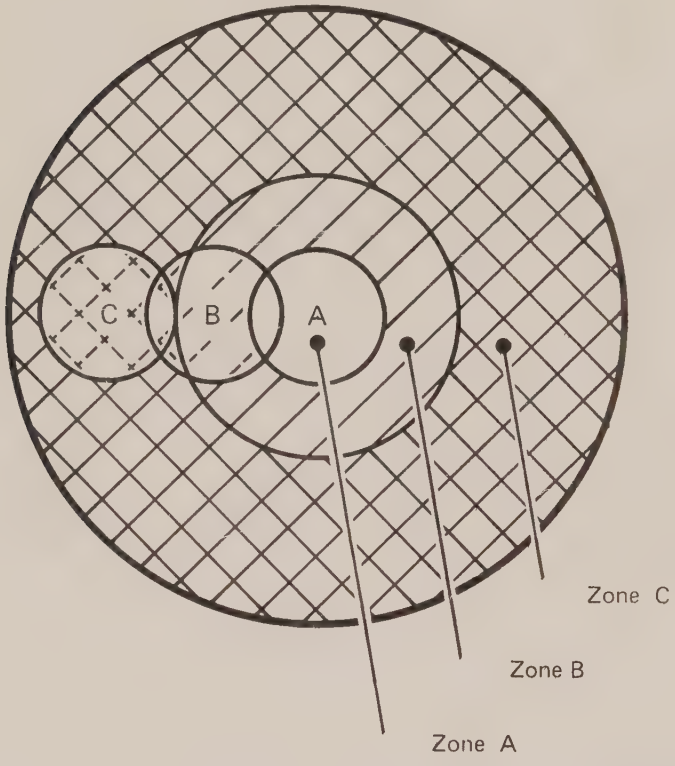


Figure 14. Three positions A, B and C in which, in random sequence, a TSK flowmeter was placed to monitor flow through concentric zones A, B and C of the Gulf III exhaust.

Since it was possible that the amount of plankton in the cod-end might affect the flow profile in the exhaust, the catches were preserved in 4% formaldehyde and their dry weight determined later. The flowmeter readings at each position, together with the corresponding dry weights are shown graphically in Figure 15. For positions A and B there is some indication that as the plankton catch increases the number of flowmeter units decreases. For position C, the data can be interpreted as showing no relationship between flowmeter units and plankton catch. However, although such a relationship as is suggested by Figure 15 is logical, the relationship is at best a poor one. No doubt the type of plankton, the period during the haul when the bulk of the catch was filtered, and the way it was first deposited on the filtering 'cone' and cod-end will all affect the flowmeter readings.

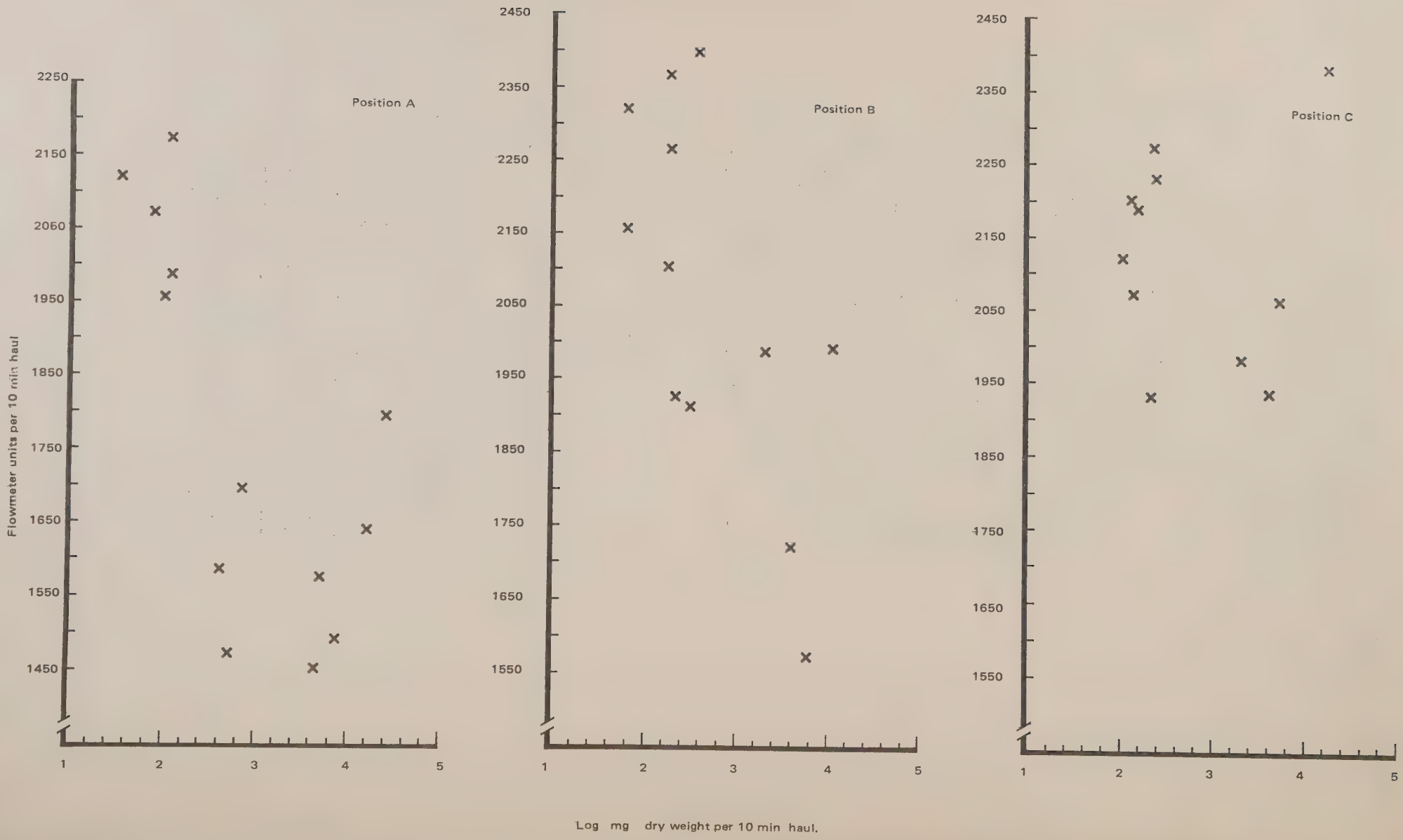


Figure 15. TSK flowmeter revolutions per 10 minute haul plotted against log dry weight of zooplankton caught per 10 minute haul of the Gulf III.

In view of the considerable variation in the number of flowmeter readings per 10 minute haul at any one position, an average for each position was the best that could be obtained.

These were:

Position A	1,786 revolutions
Position B	2,057 revolutions
Position C	2,122 revolutions

Assuming that the flow through the TSK flowmeter at positions A, B and C were representative of flow through zones A (0.003 m^2), B (0.036 m^2) and C (0.091 m^2), then 0.76 m^3 of water was passing through zone A, 10.55 m^3 through zone B, and 27.52 m^3 through zone C, a total of 38.83 m^3 per 10 minute haul. These findings were used when converting flowmeter revolutions to a volume of water filtered.

A Study of the Effect of Flowmeter Position (Mouth or Exhaust) on the Estimation of the Volume of Water Filtered

The exhaust mounting of the flowmeter in the Gulf III was at first considered one of the advantages of this sampler; Fraser (1962) for example, states, 'the flow meter, or depth/flow meter, can be fitted in this narrow tail part where it is protected and where it will register the water-flow that has actually passed through the net - a much more accurate way'. By the late 1960s, however, some doubts were expressed and Gehringer and Aron (1968) claimed that to estimate the total volume filtered from an exhaust mounted flowmeter was unrealistic.

In view of these doubts an experiment was carried out to study the effect of flowmeter position on the estimation of volume of water filtered; this investigation was done from the new FRV 'Clupea'.

A series of 90, approximately 10 minute horizontal hauls, were made at approximately 30 m depth, with a TSK flowmeter placed centrally either in the mouth, in the exhaust, or in both the mouth and the exhaust. These alternatives were repeated in a random sequence and furthermore the two TSK flowmeters were switched from mouth to exhaust in a random fashion.

The basic data obtained are given in Tables IV and V where they are arranged by haul sequence (as indicated by sequence of haul members where C69 refers to the vessel and the year).

Table IV

Volumes of water filtered based on the readings from a TSK flowmeter mounted in the mouth of the Gulf III

Flowmeter in mouth only			Flowmeter in mouth and exhaust		
Haul No.	TSK No.	Calculated volume filtered m^3/10 min	Haul No.	TSK No.	Calculated volume filtered m^3/10 min
C69/200	1540	40.0	C69/202	1540	29.0
207	"	16.8	208	"	9.7
212	"	15.4	213	"	6.3
219	"	8.6	218	"	5.6
224	"	9.3	225	"	4.3
227	"	6.4	229	"	5.8
234	"	5.6	235	"	7.5
239	"	3.9	240	"	7.6
246	"	4.3	245	"	9.9
251	"	8.0	252	"	5.9
254	"	2.9	256	"	2.6
261	"	6.2	262	"	6.4
266	"	5.5	267	"	1.9
273	"	4.6	272	"	4.4
278	"	2.3	279	"	2.3
281	"	2.0	283	"	2.3
288	"	1.8	289	"	5.1
205	1541	21.7	203	1541	35.3
209	"	18.6	211	"	11.2
217	"	10.0	216	"	6.0
223	"	5.9	222	"	12.2
232	"	6.0	230	"	14.5
236	"	8.4	238	"	8.0
244	"	6.4	243	"	4.1
250	"	4.0	249	"	4.2
259	"	5.8	257	"	7.7
263	"	2.3	265	"	2.0
271	"	2.0	270	"	6.0
277	"	5.7	276	"	6.8
286	"	5.3	284	"	5.5

Table V

Volumes of water filtered based on the readings from a TSK flowmeter mounted in the exhaust of the Gulf III

Flowmeter in exhaust only			Flowmeter in exhaust and mouth		
Haul No.	TSK No.	Calculated volume filtered m^3/10 min	Haul No.	TSK No.	Calculated volume filtered m^3/10 min
C69/204	1540	16.2	C69/203	1540	23.0
210	"	7.0	211	"	9.8
215	"	9.7	216	"	15.9
221	"	7.1	222	"	9.3
231	"	6.5	230	"	6.5
237	"	5.1	238	"	7.3
242	"	7.1	243	"	7.0
248	"	8.1	249	"	8.1
258	"	6.4	257	"	7.3
264	"	3.8	265	"	4.8
269	"	3.9	270	"	6.9
275	"	5.2	276	"	7.0
285	"	6.8	284	"	7.2
201	1541	30.0	202	1541	23.8
206	"	11.0	208	"	9.6
214	"	11.4	213	"	10.3
220	"	10.3	218	"	7.1
226	"	6.0	225	"	4.3
228	"	10.8	229	"	6.3
233	"	6.4	235	"	6.6
241	"	5.6	240	"	8.1
247	"	6.1	245	"	6.8
253	"	10.4	252	"	8.4
255	"	6.4	256	"	4.8
260	"	4.6	262	"	5.8
268	"	3.2	267	"	5.2
274	"	6.0	272	"	-
280	"	6.8	279	"	4.9
282	"	5.5	283	"	5.5
287	"	5.7	289	"	6.2

In Figure 16 the unweighted moving average volume of water filtered, of order 5, as measured by the mouth- and exhaust-mounted flowmeters, are plotted against the moving average haul sequence of the same order. The marked drop in volume of water filtered was due to progressive clogging which developed despite regular hosing down of the monel metal filtering gauze at the end of each haul. Large numbers of larvacea and flagellates present at the time of the experiment were almost certainly responsible for much of this clogging. One flowmeter position did not give a consistently higher or lower estimate of the volume of water filtered than the other, although there is a suggestion that when the filtration coefficient was high (i.e. when relatively high columes of water were being filtered) the mouth-mounted flowmeter gave a higher estimate than the exhaust-mounted flowmeter, while when the filtration coefficient was low, the exhaust-mounted flowmeter gave the higher estimate. There was little to choose between the two positions at least on the evidence of the experiment.

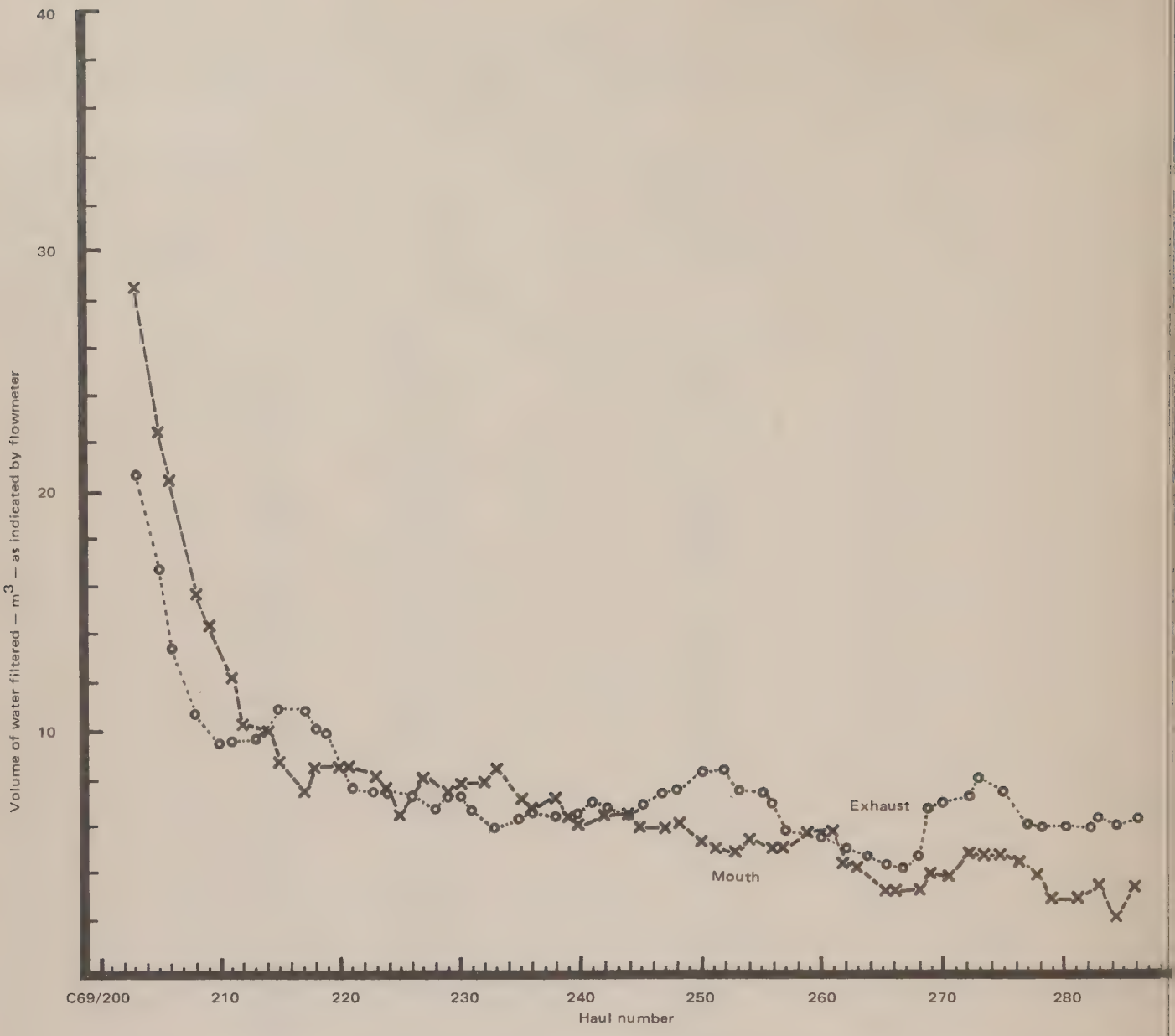


Figure 16. The unweighted moving average volume of water filtered, of order five, based on the mouth mounted and exhaust mounted flowmeters plotted against the moving average haul sequence of the same order.

Volume of Water Filtered in Relation to Duration of Haul

Although the use of the Currie-Foxton depth flowmeter became routine in 1961, flowmeter records are not available for all subsequent hauls. It was therefore desirable to be able to estimate the volume of water filtered from the duration of the haul alone. Some preliminary calculations were made using relatively few observations obtained in 1960 and 1961 but subsequently the flowmeter readings from 1961 to 1965 were used to calculate regressions in the form $R = a T + B$ where R = number of Currie-Foxton depth-flowmeter revolutions and T = duration of the haul in minutes. In the first instance regressions were calculated for a Gulf III fitted with a 60 meshes per linear inch cone for seven periods of the year to allow for possible seasonal variation in filtration coefficient (see page 34) and for a Gulf III fitted with a 40 mesh cone for one period (September - about the only month this cone was used for larval herring surveys).

Statistical examination of the data suggested that the seven regressions for the 60 mesh filtering cone could be combined to give the following:

for March $R = 0.57T + 3.2$,

for April $R = 0.73T + 0.9$,

for May and June $R = 0.53T + 2.2$,

for the months August, October, November and December,
$R = 0.76T + 0.6$.

Assuming (i) that one flowmeter revolution represented 3.8 m^3 of water filtered in March, 3.7 m^3 in April, 3.9 in May and June, 3.5 in August, 4.2 in October and 3.4 in November-December*, and (ii) that the first equation was applicable to March, the second to April, the third to May to July and the fourth to August to February inclusive, the average volume of water filtered could be estimated if the duration of the haul was known.

The regression for 40 meshes per linear inch cone in September was

$$R = 0.69T + 0.5$$

Haul Profiles

On FRV 'Clupea' the sampler was towed horizontally at maximum depth for a variable period to ensure a haul duration of at least 10 minutes. Only for depths greater than 85 m did shooting and hauling occupy the total duration of the haul.

On FRV 'Scotia' and FRV 'Explorer', shooting and hauling the Gulf III always occupied the total duration of the haul. From an analysis of the Currie-Foxton depth flowmeter records, it is possible to construct haul profiles some representative samples of which are shown in Figure 17. During shooting there was a greater depth change per flowmeter revolution than during hauling while during hauling there is some indication of a greater depth change per flowmeter revolution in the upper sampling layers than in the lower.

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*The conversion of flowmeter revolutions to a volume of water filtered is partly complicated by the shifting of the Currie-Foxton depth flowmeter in 1964 to a wider part of the exhaust, while the regressions are based on data collected during the whole period 1961-65. Allowing for the average flow profile in the Gulf III exhaust, during 1961 to 1963 one revolution represented 3.4 m^3 and since early 1964 one revolution has represented 4.6 m^3. On the basis that 62% of the March data, 73% of the April data, 57% of the May data, 61% of the June data, 100% of the July data, 89% of the August data, 38% of the October data and 100% of the November-December data used in the preparation of the regressions were obtained during 1961 to 1963, the average values for each month were obtained by weighting accordingly the two values given above.

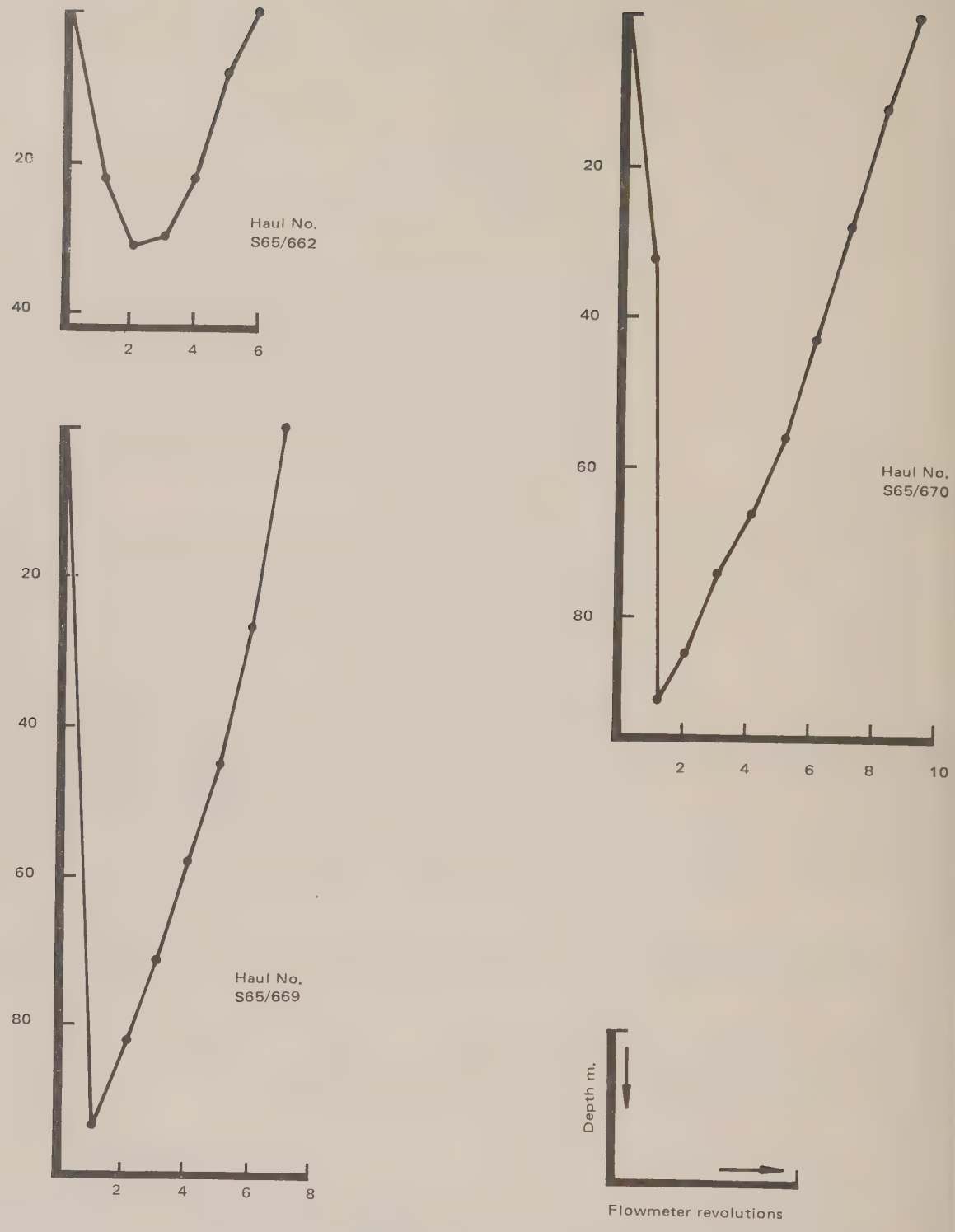

Figure 17. Some representative Gulf III haul profiles based on Currie-Foxton depth flowmeter records — FRV 'Scotia'

From measurements of depth against flowmeter revolutions, the volume of water filtered during shooting was calculated as a percentage of the total volume filtered during the haul. This percentage was related to the average warp speed as shown in Figure 18. The equation for the relationshop was

$$P = 64.0 - 0.72R$$

where P = volume of water filtered during shooting as a percentage of the total volume filtered and R = warp speed in m/min.

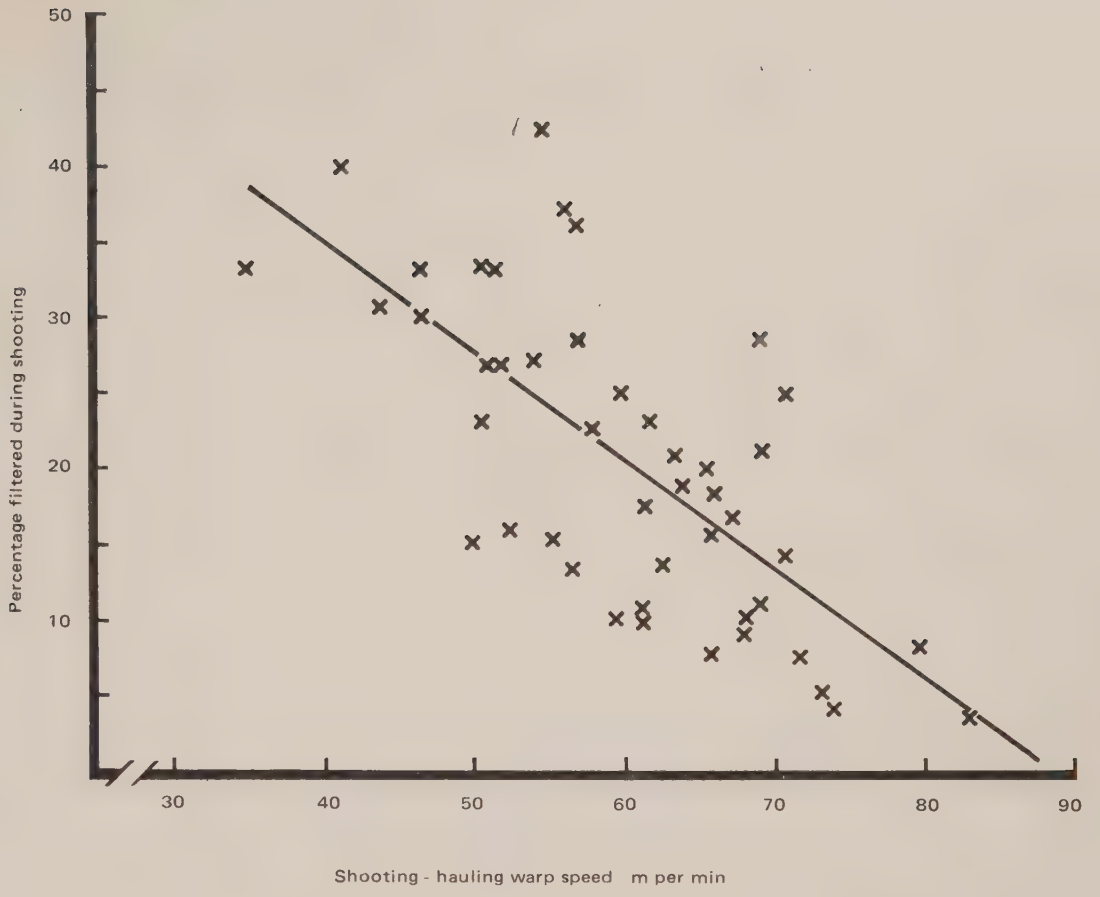

Figure 18. Volume of water filtered during shooting, as a percentage of the total volume filtered, plotted against the calculated shooting-hauling warp speed.

That less water was filtered during shooting than during hauling was due to the fact that the shooting warp speed subtracted from the ship's speed, such that the distance travelled by the Gulf III through the water during shooting was less than that during hauling. How this varies with warp speed and the difference between shooting and hauling warp speed is shown in Table VI.

By comparison of the information from Table VI with the equation relating P and R (i.e. P = 64.0 - 0.72R, Fig.19) it appears that the shooting warp speed was greater than the hauling warp speed by a factor greater than 1.9 at a shooting-hauling warp speed of 80m/min, by a factor of about 1.9 at a shooting-hauling warp speed of 60m/min and by only a small amount at a shooting-hauling warp speed of 40m/min. This evidence that the ratio of shooting warp speed : hauling warp speed varied with the average shooting-hauling speed is supported by actual records of shooting and hauling duration since, apart from two observations, the numerical value of the ratio of shooting warp speed to hauling warp speed (also shown in Fig. 19) increases, in general, from top-left to bottom right of the scatter diagram.

Table VI

Calculation of the distance travelled by the Gulf III during shooting as a percentage of the total distance travelled

Shooting - Hauling warp speed (m/min)	40		60		80	
Shooting warp speed (m/min)	58.8	40.0	88.2	60.0	117.6	80.0
Hauling warp speed (m/min)	30.8	40.0	46.2	60.0	61.6	80.0
Calculated speed of Gulf III through the water:-						
During shooting (m/min)	126.6	145.4	97.2	125.4	67.8	105.4
During hauling (m/min)	216.2	225.4	231.6	245.4	247.0	265.4
Appropriate warp length (m)	50		450		760	
Duration of:—						
Shooting (min)	0.8	1.2	5.1	7.5	6.5	9.5
Hauling (min)	1.6	1.2	9.7	7.5	12.3	9.5
Distance travelled by Gulf III during:-						
Shooting (m)	101.3	174.5	495.7	940.5	440.7	1001.3
Hauling (m)	345.9	270.5	2246.5	1840.5	3038.1	2521.3
Total distance travelled by Gulf III (m)	447.2	445.0	2742.2	2781.0	3478.8	3522.6
Distance travelled by Gulf III during shooting as percentage total distance	22.7	39.2	18.1	33.8	12.7	28.4

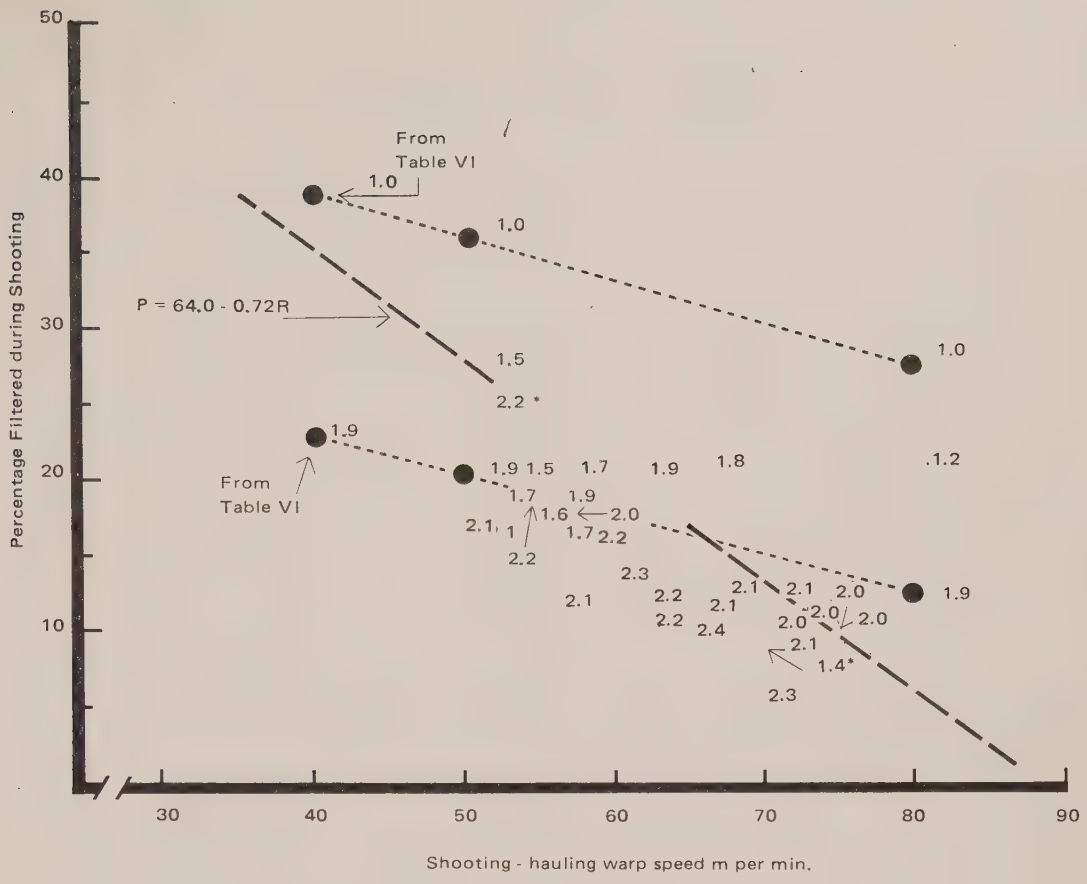

Figure 19. Ratio of shooting warp speed: hauling warp speed as observed on FRV 'Scotia' in July 1966 for hauls with various shooting-hauling warp speeds compared with the regression P = 64.0 - 0.72R (see page 28) and with shooting warp speed; hauling warp speed ratios of 1.0 and 1.9.

Depth Changes during Hauling in Relation to Flowmeter Revolution

It has already been shown that during hauling there was an indication of a greater depth change per flowmeter revolution in the upper sampling layers than in the lower. This feature will be examined further.

The Currie-Foxton depth flowmeter records for 45 hauls were examined in detail and the vertical distance travelled for each flowmeter revolution during hauling calculated. The average vertical distance travelled per flowmeter revolution interval was then calculated for all flowmeter revolution intervals for which more than 10 observations were available (Table VII). Weighting the data points by the number of observations, the least-squares equation was found to be

$$D = 8.474 + 0.1815\,S$$

where D = vertical distance travelled per flowmeter revolution in metres

and S = flowmeter revolution sequence, where 3 is to be taken as meaning 'from the 3rd to the 4th revolutions' etc.

Table VII

Vertical distance travelled by a Gulf III per flowmeter revolution[1)]

Flowmeter revolutions	No. of observations	Average vertical distance travelled per flowmeter revolution (m)	Range[2)] (m)
3-4	25	9.0	3.7-14.5
4-5	30	9.0	4.1-32.2
5-6	38	9.8	1.4-19.3
6-7	37	9.2	2.8-21.4
7-8	35	9.6	3.7-20.7
8-9	34	10.3	2.2-19.0
9-10	31	10.9	2.2-21.4
10-11	26	10.2	2.1-20.7
11-12	24	10.1	2.8-13.8
12-13	20	10.1	3.4-18.6
13-14	20	11.2	3.2-23.4
14-15	17	9.8	3.0-17.9
15-16	16	10.5	4.8-22.0
16-17	15	10.7	4.1-14.2
17-18	15	11.9	6.9-17.1
18-19	13	13.6	6.2-21.6

1)
Data for fewer than 3 revolutions and more than 19 revolutions have been excluded owing to the small number of observations available (1-8).

2)
The great range of values for any particular number of flowmeter revolutions is largely due (i) to the fact that, for example, the 4th revolution may be near the beginning of a long haul or near the end of a short haul and (ii) to variations in clogging.

In view of the considerable variation in the original data it is impossible to be confident about the result of any attempt to use the above equation to calculate changes in filtration coefficient (see below) during hauling. However, an attempt by the present author suggested that the filtration coefficient at the time of, for example, the 16th to 17th revolution was lower than the filtration coefficient at the 4th to 5th revolution by a factor of 0.93.

The Filtration Coefficient

The ability of a plankton sampler to accept and filter water has been expressed in various ways (Anon, 1968; Le Fèvre, 1973), but there is some doubt about the usefulness of the various definitions which have been used (Harding and Arnold, 1971). It is the aim in this section to give some indication of the relationship between the expected and the actual volumes of water filtered, and for convenience the expression 'filtration coefficient' has been used. This may be defined as the ratio of the volume of water accepted by the sampler, complete with net, to the volume of water through which the mouth is towed, the latter being equal to the mouth area (A) multiplied by the distance towed (D).

On the basis of the regressions given on page 27, the average volume of water filtered in hauls of 5, 10, 15, 20 and 25 minutes' duration was calculated, while the volume of water which one could expect the sampler to filter was calculated as set out in Table VIII. These latter values were considered as unity and the filtration coefficients expressed accordingly (Table IX). Three features should be commented upon.

Table VIII

Calculation of the volume of water swept by the mouth of the Bridger version of the Gulf III high speed plankton sampler during oblique hauls from near bottom to surface

	Duration of haul - minutes[1]				
	5	10	15	20	25
Approximate depth at sampling position (m)	47	75	112	170	〉200
Warp length (m)	70	215	380	630	760
Shooting-hauling warp speed (m/min)[2]	28.0	43.0	50.6	63.0	60.8
Shooting speed[3]	41.2	63.2	74.4	92.6	89.4
Hauling speed[4]	21.6	33.1	39.0	48.5	46.8
Calculated speed of Gulf III through water[5]:-					
During shooting (m/min)	144.2	122.2	110.0	92.8	96.0
During hauling (m/min)	207.0	218.5	224.4	233.9	232.2
Duration of:-					
Shooting (min)	1.70	3.40	5.11	6.80	8.50
Hauling (min)	3.24	6.50	9.74	12.99	16.24
Distance travelled by Gulf III during[6]:-					
Shooting (m)	245.1	415.5	567.2	631.0	816.0
Hauling (m)	670.7	1420.2	2185.7	3038.4	3770.9
Total distance travelled	915.8	1835.7	2752.9	3669.4	4586.9
Volume swept (m^3) [7]	20.2	40.5	60.7	80.9	101.0

Notes (1) Since the calculations refer to oblique hauls, the range of haul durations reflects a range of depths: 5 and 10 minutes-waters less than 100 m; 15 and 20 minutes-waters of 100 m and over but less than 200 m; 25 minutes - 200 m and deeper.

(2) Warp length x 2 divided by corresponding haul duration.

(3) Shooting-hauling warp speed x 1.47 - see page 9.

(4) Shooting-hauling warp speed x 0.77 - see page 9.

(5) Ship's speed (6 knots or 185.4 m/min) minus shooting warp speed during shooting, and ship's speed plus hauling warp speed during hauling.

(6) Shooting duration multiplied by speed of Gulf III through the water during shooting and hauling duration multiplied by speed of Gulf III through the water during hauling.

(7) Total distance travelled (D) multiplied by area of month (0.032 m^2) (A) multiplied by the factor 0.68 to allow for the fact that AD overestimates the volume of water swept (Harding and Arnold, 1971).

Table IX

Filtration coefficients for hauls of from 5 to 25 minutes' duration based on the last row of Table VIII and the regression (page 27) for each of the seven months listed, together with, for 15 minute hauls, the 95% upper and 95% lower values

		Mar.	Apr.	May	Jun.	Aug.	Oct.	Nov/Dec
5 minutes	Regression	1.13	0.82	0.97	0.91	0.94	0.85	0.66
10 "	Regression	0.83	0.75	0.73	0.71	0.74	0.87	0.6
15 "	95% Lower	0.44	0.34	0.23	0.26	0.36	0.53	0.4
	Regression	0.74	0.72	0.66	0.65	0.67	0.88	0.6
	95% Upper	1.04	1.12	1.08	1.03	0.98	1.22	0.8
20 "	Regression	0.69	0.71	0.62	0.62	0.63	0.88	0.6
25 "	Regression	0.65	0.70	0.60	0.61	0.61	0.89	0.6

Firstly there appears to be seasonal variation in the filtration coefficient. This could be related to the seasonal cycles of abundance of phytoplankton, zooplankton and suspended material in the water column but little more can be said. Secondly the filtration coefficient usually decreased with duration of haul. This is almost certainly due to progressive clogging both during a haul and during a cruise; Figure 20 shows that a greater percentage of hauls of 5 minutes' duration were obtained early in the haul sequence of any particular cruise than the percentage of hauls of from 10 to 25 minutes' duration.

Thirdly the fact that the average of the filtration coefficients based on the 95% upper limits is close to 1.0 suggests that the volumes of water filtered as calculated from the results obtained with the Currie-Foxton depth flowmeter were reasonably accurate.

Because of the indirect method used to calculate the filtration coefficients presented here, it is difficult to compare them with those reported previously for various versions of the Gulf series of samplers, but the interested reader should refer to Bridger (1958), Beverton and Tungate (1967), Harding, Nicols and Tungate (1969), Harding and Arnold (1971), Boucher and Thiriot (1972) and Le Fèvre (1973).

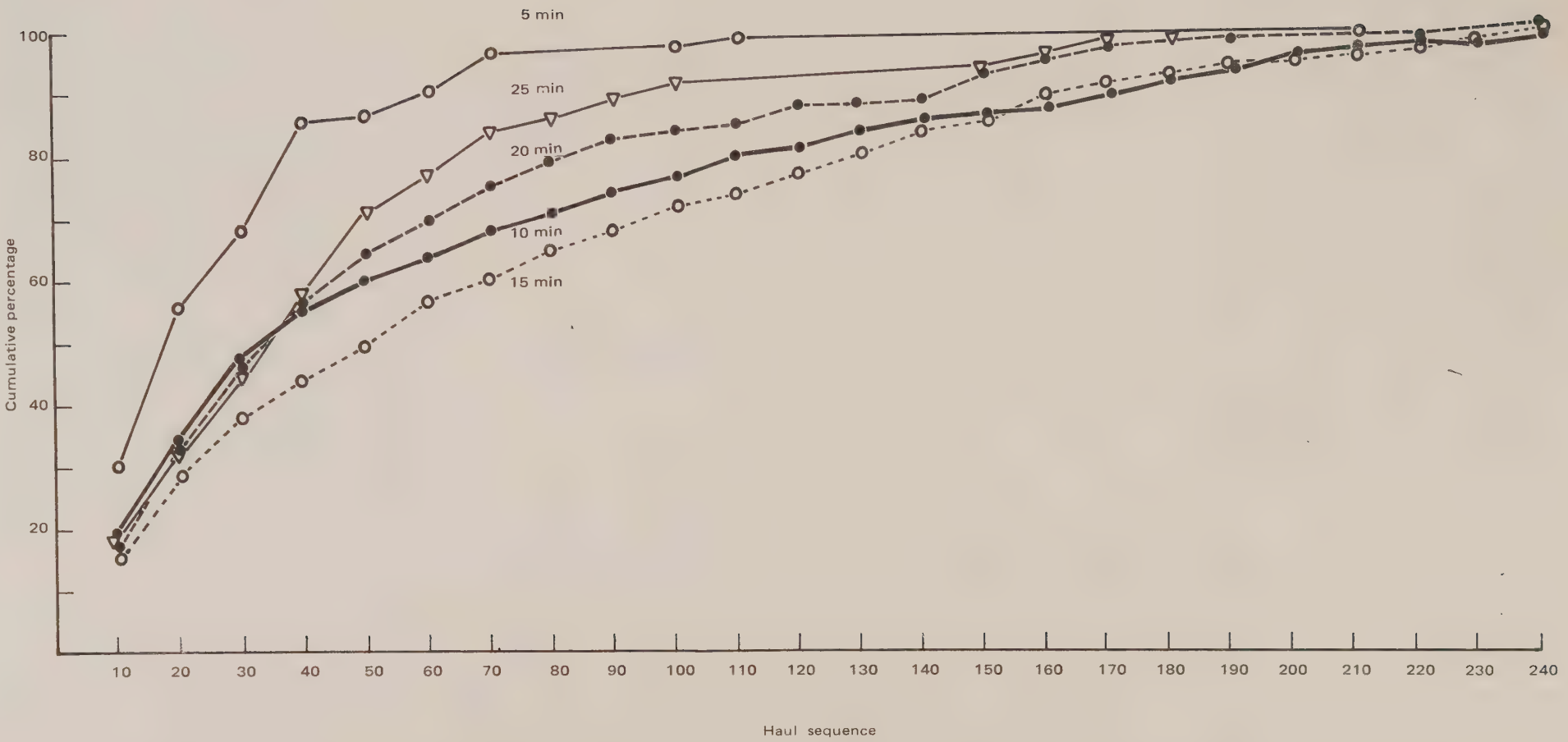

Figure 20. Distribution of Gulf III hauls of from 5 to 25 minutes' duration in relation to the sequence of hauls from the beginning of a cruise. For example, 68.1% of all hauls of 5 minutes' duration were taken within 30 hauls from the beginning of a cruise while 37.2% of all 15 minutes' hauls were taken within 30 hauls from the beginning of a cruise.

Mesh Selectivity

During 1963 attempts were made to study the mesh selectivity of 60 mesh monel metal using a Gulf III to which a small nylon mesh nylon cover of 0.069 mm mesh aperture (180 meshes per linear inch) was attached as shown in Figure 21. In designing the attachment of this cover, an attempt was made to ensure that water escaping from the Gulf III at the junction of the exhaust and body sections would pass through the cover. Thus the canvas section of the cover was securely attached to the exhaust section of the Gulf III at four points, but between these points the canvas was free to billow outwards, allowing water to pass backwards. From these points of attachment the canvas extended forwards to cover the small gap at the junction of the exhaust and body sections, and at a point anterior to this it was tied tightly against the side of the Gulf III by a pursing string, passed through rings sewn to the canvas.

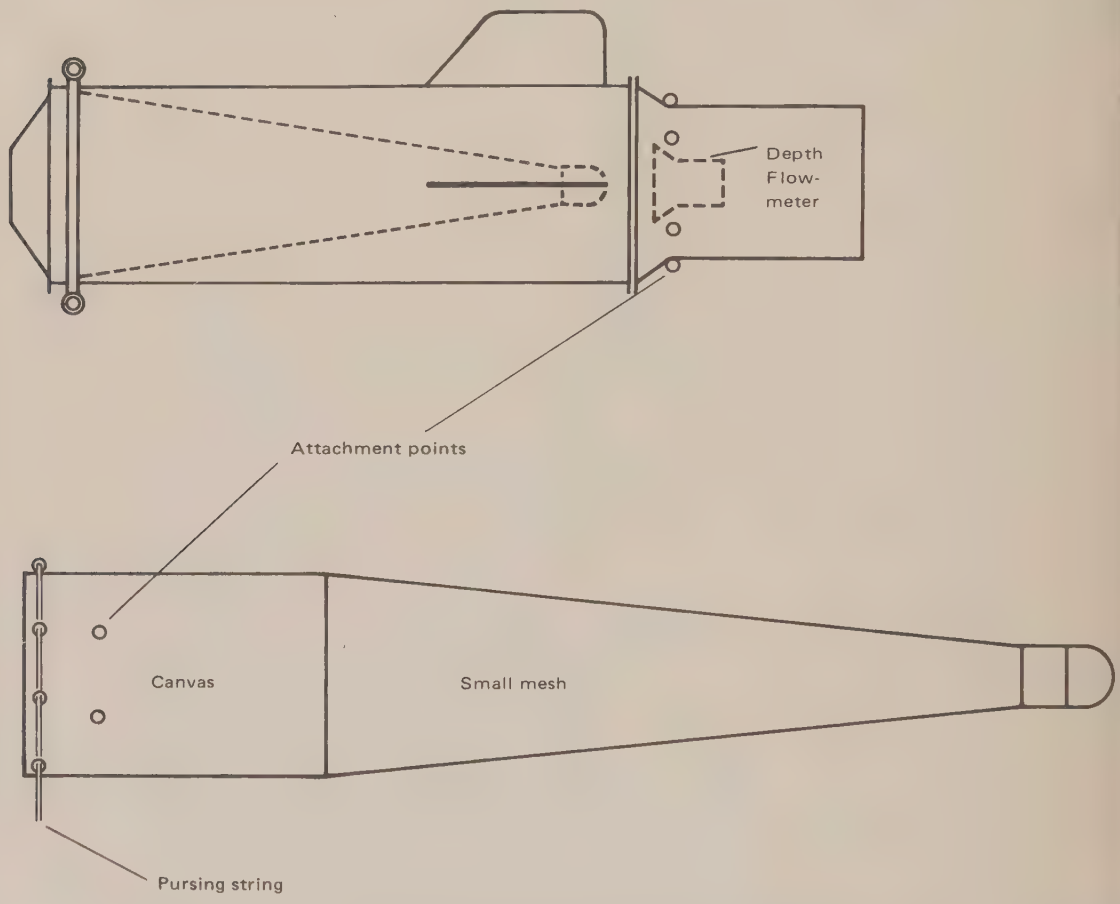

Figure 21. General outlines of the Bridger version of the Gulf III and of the small mesh cover used in the mesh selectivity experiments.

Unfortunately the pursing string frequently became loose so that water and organisms in it could pass directly into the small mesh cover. This gave the impression that a greater percentage of the organisms had escaped through the 60 mesh filtering gauze than in fact had. Examination of the data on the numbers of post larval and adult euphausiids which were present in the small mesh cover (these forms could only have passed in directly) suggested that at the worst the error introduced was about 10%. In other words, when the data suggested that 50% of a particular organism had been retained, up to 60% could actually have been retained; this will have only a negligible effect on the 50% retention length suggested by our experiments. The actual complete retention length could have lain as low as the 90% retention length obtained in the experiments but there can have been no effect on the complete release length.

In the laboratory the numbers of each type of organism in the '60 mesh cone' and '180 mesh cover' samples were either counted directly or

estimated using a Stempel pipette. Measurements of the length of the cephalothorax of 100 copepods were made from each sample while the distance from the centre of the eye to the hind margin of the sixth abdominal segment was measured for all post larval and adult euphausiids.

The percentages of the individuals of various 'species' retained by the 60 mesh gauze are listed in Table X, together with the results obtained by Saville (1958) using 60 mesh silk nets of 1 m mouth diameter; agreement between the present results and those given by Saville is reasonable.

Table X

Percentages of individuals retained by 60-mesh monel gauze in present experiments and those reported by Saville (1958) for 60-mesh silk

	Percentage of catch retained by 60-mesh gauze			
	Silk	Monel gauze		
	Saville (1958)	April 1963	May 1963	August 1963
Number of samples	16	7	2	16
Nauplii (large)	13.2	-	-	-
(small)	1.5	-	-	-
Copepod eggs	-	0.0	-	-
Nauplii	-	10.6	2.6	0.0
Calanus (adults)	99.3	78.3	99.8	87.7
(copepodites)	79.6			
Pseudo/Paracalanus	47.8	87.5	62.6	56.6
Acartia sp.	62.1	80.0	39.7	42.9
Temora longicornis	87.0	85.7	94.4	95.5
Centropages hamatus	-	90.9	87.5	92.6
C. typicus	-	-	-	99.9
Metridia lucens	93.4	96.8	48.2	98.4
Microcalanus sp.	22.4	0.0	-	-
Oithona sp.	8.0	4.2	17.2	5.0
Micosetella sp.	-	-	-	0.0
Harpacticids	0.5	-	-	-
Podon sp.	-	-	96.6	87.7
Evadne nordmanni	68.3	-	-	84.7
Euphausiid calyptopis	-	-	100.0	-
furcilia	-	-	93.8	98.6
Thysanoessa inermis	-	-	-	97.5
Spiratella retroversa	-	-	100.0	79.8
Oikopleura sp.	60.5	61.5	13.6	13.9
Sagitta elegans	-	100.0	100.0	97.1
Aglantha digitale	-	-	-	100.0
Cirripedia nauplii	-	50.0	55.6	96.8
cyprids	-	100.0	77.7	67.8
Echinoderm larvae	-	71.4	-	47.4
Gastropod larvae	10.9	-	-	-
Lamellibranch larvae	28.0	-	0.0	25.8
Polychaete larvae	13.0	62.5	-	30.0
Tornaria larvae	-	100.0	-	-
Decapod larvae	-	-	-	99.5
Cyphonautes larvae	-	-	50.0	83.3
All organisms (including those excluded from the list above)	-	35.7	48.1	48.2

In Figure 22 the mesh selection curve for all copepods combined is shown, the percentage retained being plotted against cephalothorax length and calculated total length.

A marked feature of the results shown in Table X was the large variation between months in the percentage of certain species retained. Although some of the variation will have resulted from errors in estimating the numbers present in the two samples, there are certain species with an average cephalothorax size of from 0.50 to 0.82 mm, (for example, *Pseudocalanus elongatus, Paracalanus parvus* and *Acartia* sp.) where small seasonal differences in size apparently resulted in large variation in the percentage retained.

Saville (1958) showed that organisms are released at a greater width than is compatible with a rigid square mesh and he suggested that this was due partly to a capacity on the part of the organism to be compressed and partly to a distortion of the meshes. Heron (1968) and Heron and Kerr (1968), however, showed that variation in mesh size alone can contribute to escape being greater than expected. Since escape is here considered in relation to length, it is interesting to compare the length below which complete release occurs with the size of the mesh aperture. From Figure 22 the length of complete release for copepods is seen to be 0.36 mm. This compares with a mesh aperture of 0.270 mm; no doubt the flexibility of the abdomen at its attachment to the cephalothorax will help the escape of those copepods which do not approach the mesh at an angle of 90°.

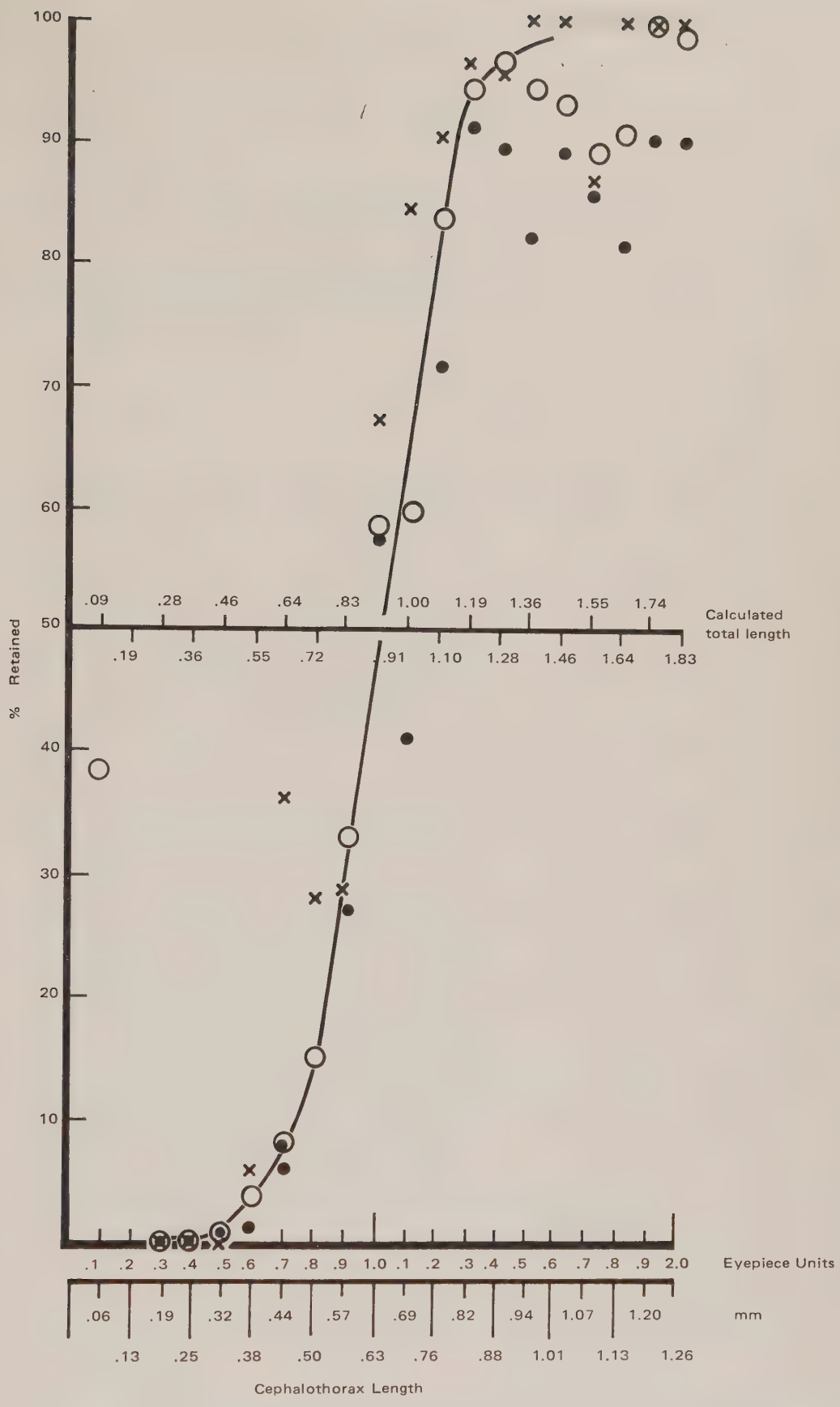

Figure 22. Copepod selection curve for a Gulf III fitted with a 60 mesh monel metal gauze, related to copepod cephalothorax length and to calculated total length. Data obtained in April 1963, ●; May 1963, X; August 1963, O. (The apparent retention of 38% of copepods at 0.06 mm cephalothorax length is based on data for only three copepods, one of which was in the '60 mesh cone' samples. This data point can be ignored.

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Summary

The Bridger version of the Gulf III high speed plankton sampler has been used by the Marine Laboratory, Aberdeen, for many of its larval fish and other zooplankton investigations. It may be useful therefore to place on record a detailed account of the Laboratory's use of this sampler.

Specifications are given of the sampler and of associated items (towing warp, swivels, depressor, drogue) together with details of (i) handling arrangements on four of the Laboratory's research vessels; (ii) losses and their causes; (iii) shooting and hauling warp speeds; (iv) depth of operation and its determination; and (v) the estimation of the volume of water filtered.

In addition, field or desk studies of various aspects of the sampler are presented. These include (i) a largely inconclusive investigation of the effect of the type of cod-end (bucket or bag) on the size of the zooplankton catch; (ii) field measurement of the tension in the towing warp which suggested that when towing at 6 knots the tension does not normally exceed 0.5 t but that hauling increases the load; (iii) an attempt to study the flow profile in the Gulf III exhaust which suggested that the quantity of plankton caught affected the flow through a flowmeter placed centrally in the exhaust; (iv) a study of the effect of the flowmeter position on the estimation of the volume of water filtered which showed that a flowmeter in one position (the mouth) did not give a consistently higher or lower estimate of volume of water filtered than a flowmeter in the other (the exhaust); (v) a desk study of the filtration coefficient which showed that the filtration coefficient varied with season and decreased with haul duration, the latter decrease being due to progressive clogging both during a haul and during a cruise; and (vi) a mesh selectivity study of 60 meshes per inch monel metal mesh.

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